

# IT PORTFOLIO SELECTION AND IT SYNERGY

BY

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## **ABSTRACT**

This dissertation consists of three chapters. The primary objectives of this dissertation are: (1) to provide a methodological framework of IT (Information Technology) portfolio management, and (2) to identify the effect of IT synergy on IT portfolio selection of a firm.

The first chapter presents a methodological framework for IT project selection. As the size of IT investment in firms dramatically increases, the demand for strong methodologies of IT project selection increases. We use the efficient frontier as a tool to solve the IT project portfolio problem. We propose a model of IT portfolio selection with this view. Our method is unique in that IT synergy measures are systemically incorporated in the portfolio selection.

The second chapter examines how firms can use IT synergy to optimize their IT portfolios. We begin by developing a framework for IT portfolio selection by identifying three types of IT synergy. Next, we examine the effect of different types of synergy on the IT portfolio selection by using this framework. Analytical models are developed to present the roles of different types of synergy. The analysis in this paper establishes conditions where firms obtain superior IT portfolios by enhancing IT synergy.

In the third chapter, we develop a project portfolio selection model, focusing the issues of the non-linear return/risk relationship of IT investment and non-standardized measures of IT risk. Taking advantages of the benefits of the DEA method, we present a project selection model and an extended model, and demonstrate the validity of the model using computational studies.

*To my Wife and my Parents*

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# **CHAPTER 1. IT PROJECT PORTFOLIO SELECTION: THE EFFICIENT FRONTIER AS A TOOL OF PORTFOLIO SELECTION**

## **1. Introduction**

As the role of IT in the firm becomes greater, IT spending has become one of the largest portions of all spending in many firms, and so IT investments become an important factor that determines a firm's performance. Considering the fact that average IT spending in a firm is ~4 to 11% of sales revenue and ~20 to 22% of the total operational cost (Kersten and Verhoef 2004), the amount of spending for IT in a firm is quite critical for the business performance of the firm. Firms desire to maximize business value from IT investments by optimally selecting their IT portfolio. However, there are few widely accepted methodologies with which IT managers can optimize their IT resources. In this regard, we propose an optimization method for firms to use to make strategic decisions in selecting their IT projects.

In this study, we define IT portfolio as a set of IT projects in a firm, although it could indicate a broader concept. Jeffery and Leliveld (2004) defined IT Portfolio Management as “to manage IT as a portfolio of assets similar to financial portfolio and to strive to improve the performance of the portfolio by balancing return and risk.” We focus on IT projects because most IT systems and components in a firm are generally to be customized for the organization through IT projects. In addition, according to our surveys

with CIOs and senior IT managers in industry, one of their main concerns is to select IT projects among proposals of IT projects or initiatives.

Our model for IT project portfolio selection is unique in that our framework incorporates the concepts of both risk management and IT synergy enhancement. First, we view the problem of IT project portfolio selection as one of balancing return and risk. Although performance of IT investment has two major dimensions – return and risk, IT portfolio selection models predominantly evaluate IT portfolios in terms of returns (Tanriverdi and Ruefli 2004). The practice of not considering risks in IT portfolio selection may result in the high failure rate in IT projects: according to the Hackett Group, three in 10 major IT projects fail and, according to the Standish Group, just 29 percent of IT projects were completed on time, within budget, and with features and functions originally specified by the customer to deliver business value (Baltzan and Phillips 2009). Second, our model incorporates IT synergy measurement. IT resources can be distinguished from other forms of resources by their great potential to create synergy. However, major IT project selection models such as scoring models do not consider IT synergy in evaluating project values. By incorporating both IT synergy measurement and IT risk, our framework can also be used to identify the relationship between the IT synergy enhancement and the risk of IT investment.

Our study is motivated by the following question: How do firms achieve the optimal IT project portfolio? In particular, how do they accomplish the optimal balance between the return and the risk of their IT investment? The purpose of this study is to provide a methodological framework that can help firms make strategic decisions on their



enterprise IT investments. We develop an optimization model and illustrate an example of IT portfolio selection. This research can provide a foundation for creating a decision support system that will enable IT managers to optimize their IT portfolio.

## **2. Theoretical Background**

### ***2.1. Markowitz's Portfolio Selection Theory and Efficient Frontier***

A general definition of portfolio is a collection of investments held by an institution or a private individual. An essence in financial portfolio selection theories is to balance the two sub-objectives: maximizing return and minimizing risk. Maximizing return is one of the most obvious objectives of economic entities. In addition, investors have the objective of minimizing risk because they practically have limited budget and cash flow. A key idea in Markowitz's portfolio selection theories lies on that an investor can reduce portfolio risk simply by holding instruments which are not perfectly correlated (Markowitz 1952). This acts as a strong incentive for investors to apply the portfolio selection theory.

In our study, we use the efficient frontier as a tool that firms can identify options of the most efficient IT portfolio according to its risk threshold. In Markowitz's theory, investors should find an optimal portfolio that lies on the mean-variance efficient frontier, which is the intersection of the set of portfolios with minimum variance and the set of portfolios with maximum return (Kroll, Levy, and Markowitz 1984). An investor may have different efficient frontier, and the risk-averseness of the investor would determine an efficient portfolio among the available portfolios on the efficient frontier.

The efficient frontier can be achieved by the following optimization problems.

$$\text{Maximize } R \tag{1.1}$$

*Subject to*  $V \leq v_0$   
(other investment constraints)

*Minimize*  $V$  (1.2)  
*Subject to*  $R \geq r_0$   
(other investment constraints)

, where  $R$  is the expected portfolio return,  $V$  is the expected portfolio risk and  $v_0$  and  $r_0$  refers to the maximum risk that the investor can take and the minimum return that the investor should attain. Using the model (1.1) and (1.2), we can plot the efficient frontier with various values of  $v_0$  and  $r_0$  and the two optimization models will produce an identical efficient frontier.

## **2.2 Project Selection**

Several studies of IT project portfolio selection stressed the importance of the aggregate view in project selection and proposed a mode to overcome challenges of classical models of project selection. The classical model includes scoring models, ranking models, and checklists (Dickinson et al. 2001). The classic models are characterized by the individual project level analysis. They focus on evaluating each project with one or multiple criteria and prioritizing proposed projects. For example, scoring models evaluate a project with the sum of scores in multiple criteria (Lucas and Moore 1976, Henriksen and Traynor 1999). Bacon (1992) and Lucas and Moore (1976) discuss multiple criteria that can be used in IT project selection, including financial criteria, management criteria, and development/technological criteria. The methods are still widely used in industries according to our survey because they are simple and easy to conduct. However, these classical methods neglect interdependencies of projects. Considering significant effect of interdependencies between IT projects, these methods may yield sub-optimal solution in

the IT portfolio selection. Thus, as an alternative of classical techniques, several researchers proposed project portfolio selection models, stressing on the interdependencies of projects.

Several models of IT portfolio selection have proposed, using the data of project interdependencies (Santhanam and Kyparisis 1995, Santhanam and Kyparisis 1996, Lee and Kim 2000, Lee and Kim 2001, Dickinson et al. 1999). They emphasized the characteristics of information systems where technologies and resources are easily shared and of which benefits are interrelated. However, few models have approached to the IT portfolio selection from identifying the effect of IT project interdependencies on portfolio return and risk. Table 1.1 summarizes the literature of project selection by the types, techniques of project selection and the focuses of each paper.

### ***2.3 Synergy in IT Portfolio***

For IT resources, two types of synergies have been discussed (Tanriverdi 2005). First, sub-additive cost synergies have been enhanced by the economics of scope that can be attained through related diversification (Panzar and Willing 1981, Teece 1980, Teece 1982, Willing 1978). Synergistic economies arise from inputs that are shared by related businesses, and the synergistic benefits are distinguished from vertical economies and financial economies (Hill et al. 1987). Resource relatedness refers to the use of common resources across units. According to the resource-based view of the firm, the use of common production factors across units creates synergies, which are sub-additive production cost synergies (Farjoun 1998, Robins and Wiersema 1995, Tanriverdi 2006). Second, super-additive value synergies can be derived from Edgeworth complementarities,

in which “doing more of one thing increases the returns to do more of another” (Milgrom and Roberts 1995). Resource complementarity is a major source of cross-unit synergy (Tanriverdi and Venkatraman 2005). According to the economic theory of complementarities (Milgrom and Roberts 1995), a set of resources is complementary when the return from a resource varies in its level of return from those of other resources. A complementary set of resources creates super-additive value synergies. Sharing and exchanging data through integration between multiple information systems enables firms to explore super-additive value synergies.

### **3. Model Development and IT Efficient Frontier**

#### ***3.1 Conversion from Financial Portfolio to IT Project Portfolio***

The portfolio selection theory has been most actively studied in the field of finance where various portfolio selection models have been developed. An essence of investment in the portfolio selection theories is to balance return and risk. As the expected return of an investment is greater, it will be more attractive to investors. But, if the risk of the investment is too high and the investor may lose a large amount of money, the investor might decide not to invest even though the expected return is very high. This principle in investment can be applied to both financial portfolio selection and IT portfolio selection. However, there are major differences between IT portfolio selection and financial portfolio selection. This gap addresses the necessity of developing models for IT portfolio selection that is distinguished from financial portfolio selection models. In this section, we discuss the differences.

*Synergy between units.* Holding multiple financial units does not create any additional return though it can reduce risk. The return from multiple financial investments is equal to the sum of returns of individual investments. However, the return of IT portfolio may not be equal to the sum of returns of individual IT investments because synergies between IT units can be created or enhanced. When two IT projects are implemented or maintained together, a firm may be able to save costs or create additional values through integration.

*Negligible Residual Value.* Reselling financial products is, in general, not too difficult even after an investor purchases them because the market value of financial products does not change depending on the owner of the financial products. However, after an organization invests in an IT project, the value of the ongoing IT project to the organization is much greater than the value of the IT systems to other organizations. The intricacy in canceling decisions of IT investment would lead to the greater impact of the investment risk in IT portfolio selection. Thus, selecting IT projects should weigh portfolio risk no less than financial investment does. To reflect the greater importance of risk in IT portfolio selection, we regard minimizing portfolio risk as a sub-objective function of our portfolio selection model and develop our model as a bi-criteria optimization model.

*Risk Factors.* The volatility of IT portfolio return is influenced both by the uncertainty of its future benefit (value) and by the uncertainty of its cost whereas the volatility of financial portfolio return is affected solely by the future value, but not by the cost. Thus, the factors that affect the risk in IT investment are different from the factors in financial investment. The return can be defined as  $\text{return} = \text{value} - \text{cost}$ . The risk refers to

volatility of the portfolio return, which can be represented by statistical terms such as standard deviation or variance. In most cases of financial investments, there is little uncertainty in the cost of purchasing financial products because financial products have their market price. This indicates that the portfolio risk in financial investment is determined only by the volatility of the value. On the contrary, the cost of an IT project is often very uncertain. Although IT experts estimate the cost of individual IT projects, the cost of IT projects often turns out to be greater than the estimation and the underestimation of the cost leads to the project failure (Keil 1995). Therefore, both the uncertainty of the benefit and the cost affects the portfolio risk in IT portfolio selection, unlike in financial portfolio selection where only the uncertainty in the cost does rarely affect the portfolio risk.

*Binary Value of Decision Variables.* In financial portfolio, decision variables are either the number of units of a financial product or the amount dollars spent to purchase a financial product. However, in the IT project selection, unlike decisions for financial products which can be bought multiple units, the decision is either to select or not to select proposed projects in most cases. Thus, the decision variable in the project selection problem is a binary one which represents whether a project is selected or not. Another possible value for the decision variable is to be partially funded because, in practice, some projects are decided to be supported only partially. But, in this study, we exclude this case and assume every decision is either to be selected or not for a simplicity reason because the modified proposal of an IT project can be regarded as a different IT proposal in terms of scope, cost, and benefit of the project. In addition, “being held” can be another decision for an IT project, which may require real option methods. However, we also exclude the hold

decision because, in practice, the profiles of an IT proposal may need to be updated and the proposal can be regarded as a different IT proposal after being held for a while, considering dynamic environment of information technology investment.

### ***3.2 A Framework for IT Project Portfolio Selection***

One of the most common issues in prior frameworks of IT project portfolio selection is that a firm has multiple objectives and that those multiple criteria are often conflicting (Ghasemzadeh and Archer 2000, Dickinson et al. 2001). Financial criteria, strategic alignment, interdependencies, probability of project success and other possible criteria are considered as a firm's multi-objectives to achieve. However, the multi-objectives can be represented by the two independent sub-objectives – maximizing return and minimizing risk when we consider the fact that the ultimate concern of a firm is monetary value of its investment. For example, reasons that a firm wants to achieve IT alignment with strategy and to enhance IT synergies would be to maximize return, and firms desire to reduce risk of their investment because of their financial constraints. Therefore, the project portfolio selection problem can be simplified into the problem of balancing return and risk.

Our framework in Figure 1.1 demonstrates the major difference from a framework of financial portfolio selection. In the framework of IT portfolio selection, interdependencies – synergy and covariance – affect both portfolio return and portfolio risk. Whereas, in the financial portfolio selection, only covariance exists between financial products and it does not affect portfolio risk only.

In our model, the expected portfolio return is defined as the expected benefit (value) minus the expected cost. The portfolio risk is defined as the volatility of the expected portfolio return, which refers to the degree of uncertainty of the expected portfolio return conceptually and the standard deviation of the return statistically. Since our definition of the expected risk conceptually represents mathematical term standard deviation of the portfolio return, the risk of IT portfolio can be defined as the sum of the volatility of the benefit and the volatility of the cost by applying mathematical properties of the variance. Because, unlike financial products, IT projects rarely have sufficient historical data that can be used to calculate mean and variance of the benefit and the cost, we assume that experts in the firm can reasonably estimate those expected values and each firm has its own consistent measure of the expected return and risk as we certified that firms have their own way of evaluating return and risk IT projects in our survey.

Facing the risk of IT investment, it would be reasonable for a firm to use the efficient frontier as a tool of IT portfolio selection. Any portfolio on the efficient frontier is one of the most efficient portfolios, and a portfolio can be selected depending on the risk threshold or the risk appetite of the firm. Thus, the key idea of our proposed method is that, first, we need to achieve an IT efficient frontier to find out the set of IT portfolios that are the most efficient investment at a given risk, and next, choose a IT portfolio among ones on the efficient frontier according to the risk threshold of the firm and marginal return over marginal risk of the portfolio on the efficient frontier.



### 3.3 The IT Portfolio Optimization Model

We present two models that yield the efficient frontier, which presents the set of the most efficient portfolio. To obtain an efficient frontier, we need to solve optimization models, in which the portfolio return  $R(x)$  is maximized at a given portfolio risk  $V(x)$  or  $V(x)$  is minimized at a given  $R(x)$ . Thus, the following optimization models, which we call ITPO (IT Portfolio Optimization) model, can be given:

$$\begin{aligned} & \text{Maximize } R(x) \\ & \text{Subject to } V(x) \leq v_0 \\ & \quad \text{(other constraints),} \end{aligned} \tag{1.3}$$

$$\begin{aligned} & \text{Minimize } V(x) \\ & \text{Subject to } R(x) \geq r_0 \\ & \quad \text{(other constraints),} \end{aligned} \tag{1.4}$$

where  $v_0$ , which we call the risk threshold of the firm, is refers to the maximum portfolio risk that a firm is willing to bear at a given level of IT investment, and  $r_0$  is a minimum portfolio return that the firm should obtain. The objective function can be interpreted as the problem of balancing return and risk of IT portfolio.

In this study we do not use a dynamic model for IT project selection. A dynamic model is useful when the value of the decision variables at one point is influenced by previous values of the decision variables. In the practice of the IT project selection, we believe dynamic models are less useful. Once an IT project is decided to be invested, the project is likely funded until it is completed because canceling an ongoing IT project means giving up a large financial commitment. This sequential decision over multiple periods is not likely to be functional. Although timing of IT projects can be a part of the decision and

a firm may hold decisions for some IT projects, it does not mean that we need a dynamic model. Since cost and value factors of IT project is volatile, the projects that the firm holds their decision in previous periods should be re-evaluated at the period that the project is included in the candidates of IT portfolio. In addition, since the attributes of IT projects are easily changeable in business environment, an IT project is likely to be re-evaluated at when the proposal is re-submitted.

The constraints in the IT portfolio optimization model result from unique problems of an organization's IT project selection. They may include budget constraints, logical constraints, positioning constraints (Liesio et al. 2008), threshold constraints (Kleinmuntz 2007). In addition, the decision variables of the model should have a binary value:

$$x_i = 1, \text{ if project } i \text{ is selected; } 0, \text{ if project } i \text{ is not selected}$$

Here are the assumptions: The project candidates for an IT portfolio are already undergone through screening process by individual project analysis; Projects hold in the previous period are supposed to be proposed in the following period; And the decision of partial funding of a project means the selection after modification of scope of the project.

### ***3.4 Selecting an Optimal Balance Using Efficient Frontier***

The Figure 1.2 shows the feasible area of an IT portfolio selection. The  $y$ -axis and  $x$ -axis represent the return and the risk of portfolios respectively. Each spot in the feasible area of the portfolio map indicates the return and the risk of a portfolio. The definition of the efficient frontier in our study is defined as the intersection of the set of portfolios with minimum variance and the set of portfolios with maximum return. The line in Figure 1.2 is

the efficient frontier of a sample proposed project data. Plots in right to the frontier indicate feasible portfolios that a firm can select.

Among the solutions of the optimization model, a firm needs to find the optimal portfolio depending on its risk threshold. But, many firms may not have a precise number of their risk threshold. Instead, those firms are likely to consider the marginal value they can earn by taking additional risk in a certain range of portfolio risk. The firm may want to select a portfolio where the marginal value over marginal risk is relatively small compared to the marginal value of other portfolios in the range. If the marginal value at a certain risk is significantly high, the firm can achieve the significant additional return by taking additional risk. Thus, the efficient frontier that provides information of marginal portfolio value at different portfolio risk would be a useful tool for decision makers of IT investment. If a firm has an IT portfolio efficient frontier illustrated in Figure 1.2 and the portfolio A, B, and C are the options that the firm can select. In this case, if risk of the portfolio C is in the range that the firm can bear, the portfolio C would be the most reasonable choice. It is because taking additional portfolio risk at the point C does not help the firm earn significantly greater return, whereas taking additional risk at the point B and C does. Thus, the IT portfolio efficient frontier would help firms to select an optimal IT portfolio.

## **4. Measurement**

### ***4.1 Measurement of Portfolio Return and Portfolio Risk***

In this section, we present the measurement of IT portfolio return and risk that can be used in our model. Since the evaluation of monetary benefits and costs of IT projects is one of the most important practices in IT portfolio management, it is critical for a firm to

use an appropriate measurement method. However, because each firm faces different business and managerial problems and different IT projects have different scopes, various criteria and methods can be used from firm to firm or from project to project. But, in most decision making processes of IT portfolio selection, the return and risk of feasible portfolios need to be assessed, no matter what different specific factors determine the return and the risk, for the firms to make high-level decisions in the IT investment.

Assuming the monetary benefit and the cost of an IT project take place in probability and have probability distributions, we define the risk of IT project as the standard deviation of the sum of the return. The variance of the IT portfolio unit can be calculated by the sum of the variance of the portfolio benefit and the variance of the portfolio cost because of the statistical property of variance  $Var(ax + by) = a^2Var(x) + b^2Var(y)$  when  $x$  and  $y$  are independent. According to the risk measure, both the uncertainty of the benefit and the uncertainty of the cost affect the portfolio risk in IT portfolio selection, unlike in financial portfolio selection, in which little uncertainty exist in the cost of acquiring financial products.

We define the portfolio return and the portfolio risk as:

$$R = [x' \Delta_v x - x' \Delta_c x] \quad (1.5)$$

$$V = \sqrt{x' \Sigma_v x + x' \Sigma_c x} \quad (1.6)$$

, where  $\mathbf{x} = [x_1, x_2, \dots, x_n]$ ,

$$\Delta_v = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ 0 & a_{22} & \dots & a_{2n} \\ 0 & \dots & \dots & \dots \\ 0 & 0 & 0 & a_{nn} \end{bmatrix}, \Delta_c = \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ 0 & b_{22} & \dots & b_{2n} \\ 0 & \dots & \dots & \dots \\ 0 & 0 & 0 & b_{nn} \end{bmatrix},$$

$$\Sigma_v = \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ \dots & \dots & \dots & \dots \\ c_{n1} & c_{n2} & \dots & c_{nn} \end{bmatrix}, \text{ and } \Sigma_c = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & d_{nn} \end{bmatrix}$$

Upper triangle matrixes  $\Delta_v$  and  $\Delta_c$  present the estimated monetary benefit and the estimated cost of portfolio respectively. In the matrix  $\Delta_v$ ,  $a_{ii}$  is the expected benefit of project  $i$ , and  $a_{ij}$  refers to the additional value other than the sum of benefits of project  $i$  and project  $j$  when both project  $i$  and project  $j$  are selected. In the matrix  $\Delta_c$ ,  $b_{ii}$  is the expected cost of project  $i$ , and  $b_{ij}$  is the amount of cost saving when both project  $i$  and project  $j$  are selected. The  $a_{ij}$  and  $b_{ij}$  can be considered as metrics of the super-additive value synergy and sub-additive cost synergy occurred between project  $i$  and project  $j$  (Tanriverdi 2006, Tanriverdi 2005). Matrixes  $\Sigma_v$  and  $\Sigma_c$  represent the value covariance and the cost covariance between two IT projects. The  $c_{ii}$  is the variance of the project  $i$ 's estimated benefit. The  $c_{ij}$ , which is equals to the  $c_{ji}$ , is the covariance between the benefits of project  $i$  and project  $j$ . The  $d_{ii}$  is the variance of the project  $i$ 's estimated cost. The  $d_{ij}$ , which is equals to  $d_{ji}$ , is the covariance between the costs of project  $i$  and project  $j$ . Then, we can formulate the portfolio return as  $x' \Delta_v x - x' \Delta_c x$  and the portfolio risk as the square root of  $x' \Sigma_v x + x' \Sigma_c x$ , where  $x$  is a vector of decision variables.

## ***4.2. Estimation of Portfolio Return and Risk***

Solutions of the optimization models will be meaningful only when the valid data are plugged in. However, from our surveys with IT managers, we found that different firms are using different methods of measuring IT benefits and costs. It is natural that firms have their own measures because they would have unique business problems and processes. To fill the gap between the theoretical methods and the real world, we intend to present a way of estimating IT portfolio return and risk.

### ***4.2.1 Estimation of Portfolio Return***

Firms are using various criteria in evaluating the value of proposed IT projects. Typically IT projects are assessed by financial criteria, management criteria, and development criteria (Bacon 1992). Financial criteria help firms to calculate NPV or ROI of the IT investment, management criteria include strategic alignment, compliance issues and user acceptance, and development criteria include technical maturity, and experience with the technology. Evaluation and assessment of an IT project is complicated because those criteria do not have one-dimensional metric and different organization would impose different weight on each factor. Most firms rely on their internal experts in evaluating proposed IT projects. We assume that the intrinsic monetary value and the cost of an IT project can be reasonably estimated by experts in the firm.

The benefit and cost of individual IT projects can be estimated by probability distributions of the random variables. The expected value of a random variable  $E(x) = \sum x_i p(x_i)$  where  $x$  can be the value or the cost of projects can be used as a measure

of benefit and cost of individual IT projects. In our model, the benefit and cost of the project are random variables, and the synergy between a pair of projects is a given number.

A form like Table 1.2 can be used to calculate the expected value and cost of projects. In the sample described in Table 1.2, the expected benefit on IT project A is \$100K for 25%, \$200K for 25%, \$300K for 25%, and \$400K for 25% and the expected cost is \$50K for 25%, \$100K for 25%, \$150K for 25%, and \$200K for 25%. After the inputs of each percentile for project benefit and cost are filled, and the expected benefit and standard deviation can be calculated. The expected benefit of and the expected cost of Project A in Figure 7 is calculated as \$250K ( $= 0.25*100K + 0.25*200K + 0.25*300K + 0.25*400K$ ) and \$125K ( $=0.25*50K + 0.25*100K + 0.25*150K + 0.25*200K$ ) respectively. We assume that the expected synergistic value between two projects can be estimated as a single number.

#### *4.2.2 Estimation of Portfolio Risk*

Possible factors that affect IT project risks are time, people, costs, deliverables, quality, contracts, and markets (Levine 2005, p. 115). McFarlan (1974) argues that portfolio risk are determined by project size, experience with the technology and project structure. Similar to measurement of IT project values, the risk of IT projects consists of multiple dimensions. But for decision making out of a number of proposed IT project, the risk needs to be quantified for decision makers to evaluate individual IT projects or IT portfolio.

To quantify the portfolio risk, the probability distribution can also be used to measure variance of individual projects and covariance of two IT projects in practice

because the values will be an estimated number. The variance or standard deviation of individual projects can be easily calculated using the equation  $Var(x) = E(x^2) - [E(x)]^2$  with data in forms like Table 1.2. To measure covariance between two projects, we need additional data set. Table 1.3 is a sample form that can be used to estimate covariance between two IT projects. For example, assuming there are four possible future events – I, II, III, and IV – with probability of .25 for each. The numbers in the second row indicate the values of an IT project  $r$ , for each event and the numbers in the third row indicates the value of the other IT project,  $q$ . The numbers of the third column are  $r - r'$  where  $r'$  is the expected value of  $r$ . The numbers of the fourth column are  $q - q'$ , and the numbers in the fifth are  $(r - r')*(q - q')$ . Then, according to the statistical definition of covariance, the covariance between the IT units will be 12.5B ( $= .25*15B + .25*10B + .25*15B + .25*10B$ ).

## 5. Application

In this section, we illustrate a procedure of our project selection model and an example to show the relevance of our IT portfolio framework.

### 5.1 The IT Portfolio Selection Procedure

To select an optimal, first, the firm needs to develop measurement of portfolio return and risk. Second, the firm needs to collect data of individual IT projects and interdependencies between IT projects. Third, an IT efficient frontier can be plotted by plugging the data in the IT portfolio optimization model with different risk weights. Finally, the firm can select an optimal IT portfolio using the IT efficient frontier.



*Step 1: Develop measures of portfolio return and risk.* Firms need to quantify the return and the risk of IT portfolios by developing measures of the return and the risk of individual IT projects and interdependencies between projects. First, firms need to identify factors that determine project monetary benefit, project cost, and project risk. Since different firms have different factors, different measures would be developed by different firms. Second, firms need to identify interdependencies, such as synergy and covariance.

*Step 2: Collect data.* Once IT portfolio return and risk was defined in a firm, the firm needs to collect data to calculate portfolio return and risk, in particular  $a$ 's,  $b$ 's,  $c$ 's and  $d$ 's in the matrixes of Equation (1.5) and (1.6), and to formulate constraints. Using those data, firms can calculate their estimated return and risk of IT portfolios.

*Step 3: Plug-in the project data into ITPO model and Plot the IT Efficient Frontier.* The ITPO model produces an IT portfolio with a given the risk weight. Using the data collected in Step 2 and an optimization program, the firm could get the solution of the ITPO problem. By iteratively running the model with different risk weights, the firm can plot an IT efficient frontier.

*Step 4: Find an Optimal IT Portfolio.* To find out the optimal portfolio, firms can use IT efficient frontiers. Firms can select an optimal portfolio that lies on the portfolio efficient frontier at a point where the marginal return over marginal risk is relatively low in the range of risk threshold that the firm cares.

## **5.2 An Example of IT Portfolio Selection**

In this section, we illustrate an example of IT project portfolio selection. We assume a firm has to select IT project portfolio out of 9 high-cost projects that are

interdependent. Table 1.4 describes the project data. Table 1.5 shows a part of interdependency data, which will be used to make the matrix of value synergy, cost synergy, value covariance, and cost covariance.

The model below was developed based on the data described in Table 2 and 3.

$$\text{Maximize } x'(\Delta_v - \Delta_c)x$$

$$\text{Subject to } \sqrt{x'(\Sigma_v + \Sigma_c)x} \leq v_0$$

$$x'\Delta_c x \leq 18,000,000$$

$$x_i = 0 \text{ or } 1,$$

where  $x'$  is a vector of  $(x_1, x_2, \dots, x_9)$ , and  $\Delta_v$ ,  $\Delta_c$ ,  $\Sigma_v$ , and  $\Sigma_c$  are the matrix for the value synergy, the cost synergy, the value covariance, and the cost covariance. The matrixes of IT project interdependencies are described in Appendix B. Here, \$18 million dollars in the constraints indicates IT budget of the firm. We assume there is no other important constraint in this example.

Using Lingo, which is an optimization program, we solve the IT project portfolio selection problem. Table 1.6 demonstrates the solution depending different values of  $v_0$ . For example, in case that the risk threshold of the organization is 4, the optimal portfolio for the firm is to select Project 1, 6, 7 and 9. On the other hand, in case that the firm relatively prefer taking risk and the risk threshold is 8, the optimal portfolio is to select Project 1, 3, 4, 5, 7 and 9.

Next, the firm needs to select a portfolio among the solutions. Using the solutions above, the firm can plot the efficient frontier of Figure 1.3. In this example, the firms would choose one among portfolio A, B, C, D, E, and F because those are the most efficient

portfolio at a given risk. If we assume that the range of the risk that the firm considers is from 5 to 8, we can say that the portfolio C is the most reasonable choice because the risk of the portfolio D is much higher than that of the portfolio C, but the return of the portfolio D is only slightly higher than that of the portfolio C. And because the firm can take significantly greater return by taking additional risk at the point of portfolio B, portfolio C can be preferred.

## **6. Discussion**

To discuss the benefit of using IT portfolio optimization model, we compared the results above with the solution of alternative optimization models in this section, using example we used in the example in Section 5.2.

### ***6.1 The effect of Aggregate Level Analysis***

Once firms realize the existence of interdependencies between IT projects, not considering the interdependencies would lead them to portfolio selection in an incorrect IT portfolio space, where the IT portfolio space refers to the set of {return, risk} of possible IT portfolios. Figure 1.4 demonstrates a portfolio map that plots feasible portfolios that a firm could select when it considers both synergy and covariance and when it does not consider any of them with the IT budget of \$ 18 M in a year. The efficient frontier in the cluster B results from a selection model in which IT projects are evaluated in the individual level not in the aggregate level. The line and points in the cluster A are the efficient frontier and a part of feasible portfolios selected by the model that considers both synergy and covariance. The cluster B can be an example of incorrect IT portfolio spaces that is the result of individual project level analysis of IT projects if the interdependencies between IT projects

exist. As we can see in the figure, a portfolio selection without the aggregate level analysis would lead to a selection in an inaccurate IT portfolio space and to under-optimized portfolio selection.

Next, we intend to answer for the question “what if a firm does not measure synergy when the synergy does exist?” The risk tolerance utility function  $U = R - \sigma^2 / T$  (Elton et al. 2007), where  $R$  is the portfolio return,  $\sigma$  is the standard deviation of the portfolio return, and  $T$  is the risk tolerance of the firm, is used in comparing results of the two portfolio selection models. We consider a project selection problem in the previous example, but the synergy is not measured by the firm. We assume that the probability of the 10% additional return synergy between a pair of projects is 30%.

If a firm uses the model of the individual project level, the firm would select a portfolio out of portfolios on the efficient frontier in the cluster B depending on their risk appetite. Therefore, if there is interdependencies between IT projects, information about the aggregate level analysis as well as information of the individual project level analysis will lead to the correct IT portfolio space and efficient frontier like in the cluster A, and the firm be able to select an optimal IT portfolio.

## ***6.2 The effect of Synergy***

Simply applying the Markowitz’s portfolio selection method to IT portfolio selection would make firms to miss the effect of IT synergy in their portfolio selection because, in the Markowitz theory, the interdependency between securities only affects the portfolio risk. And according to our survey, many firms do not systematically consider IT synergy when they select IT portfolio. Although most IT managers understand the

existence of IT synergy, but they often ignore the synergy. Then, what happen if the IT synergy effect, which exists, is ignored in the IT portfolio selection? First, they may not effectively allocate their IT resources and IT budget. In particular, sub-additive cost synergies allow firms to select more IT projects and then enable them to achieve greater benefits. Figure shows the objective function of IT portfolio, which is the return that is not at risk, selected through different IT portfolio selection models when the firm's risk threshold is 5%, 10%, and 25% respectively. The model of Individual Project Level Selection refers to the selection model that applies Model (1.6) without any information of IT synergies and covariance, the model of Only With Covariance refers to the model that applies Model (1.6) only with information of covariance, the model of Only With Synergy refers to the model that applies Model (1.6) only with information of IT synergy, and the model of ITPO refers to our proposed model in Model (1.6). Figure shows, for the firm that has the IT portfolio selection problem of this example, there are significant difference between the model of the individual project level selection and ITPO model in all the three cases of 5%, 10%, and 25% risk threshold. We can interpret the result that the effect of IT synergies in the example is noteworthy and missing IT synergy information in the IT portfolio selection would result in a sub-optimal IT portfolio.

### ***6.3 Validity of Synergy Enhancement***

The contribution of our project selection model is incorporation of synergy measures in the portfolio selection, where we assume that utilizing synergy is beneficial. However, for IT managers of a firm, synergy between projects is often an option. That is to say, our optimization model will be useful only when synergy enhancement can benefit the

firm. Only when a firm cannot benefit from synergy enhancement, the firm would enhance and measure the expected synergy. Thus, to validate our model, we examine whether that synergy enhancement can give firms a higher utility by using Monte Carlo Simulation.

We consider a two-project portfolio of a firm – one project implements SCM systems and the other project implements CRM systems. We assume the firm would purchase those solutions from the same vendor (e.g., they purchase both from SAP) if they intend to enhance synergy and from different vendors (e.g., they purchase CRM from Oracle and SCM from SAP) if they do not. Since we view a portfolio as a set of two relating projects, the results of the analysis of two-project portfolio can be extended for the analysis of many-project portfolio.

We compare the outcomes of the two options and examine whether the option with synergy enhancement can bring firms greater utility than the other option. We consider an example where the firm can estimate benefits and costs of the two projects, and synergies occurred between the two projects for four possible scenarios respectively. Table 1.7 and 1.8 describe the firm's estimation. For example, in the first scenario, the benefits of CRM and SCM are estimated \$100M and \$50M respectively and, if the firm purchases the two solution from the same vendor to enhance synergy, the synergy is estimated \$10M. Using the project portfolio data in those tables, we can calculate the expected benefits, the expected costs, and the variances of the benefit and the cost.

The firm's utilities under the uncertain events are compared using Monte Carlo simulation. We use the risk tolerance utility function  $U = R - \sigma^2 / T$  (Elton et al. 2007), where  $R$  is the portfolio return,  $\sigma$  is the standard deviation of the portfolio return, and  $T$  is

the risk tolerance of the firm. We run 1000 iterations and calculate the mean and the standard deviation of them. Table 1.9 compares the outcomes of the portfolio with synergy enhancement and without synergy enhancement. According to the results, the firm can benefit from the synergy enhancement. The utilities of the two cases are significantly different from the t-test. The results imply that the firm is better off synergy enhancement. Therefore, our portfolio selection model will yield more optimal solution than a model that does not incorporate synergy measures.

## **7. Conclusions**

As the role of IT has become increasingly critical to a firm's performance, the size of IT investments in large firms has increased up to tens of millions of dollars per year. From the cooperation with three US Fortune 100 firms and interviews with CIOs or senior IS managers from more than 10 companies, we found that one of the biggest challenges is that there is few methodologies for IT portfolio management. From the CIO-level IT manager perspective, IT investment would be viewed as a problem of balancing return and risk. We proposed a method of IT portfolio selection using an optimization model and the IT efficient frontier.

One of the contributions of this study is that we provide a methodological framework that helps firms to find a practical solution for their IT portfolio selection problems. We simplify unstructured multiple variables into a balancing problem between return and risk. On the other hand, theoretical contributions of our study include that we extend financial portfolio selection models into the IT portfolio selection model that reflects IT problems. Our model captures not only the essence of the general investor's

problem, namely, that of balancing return and risk, but also the characteristics of IT problems. It can be distinguished from portfolio selection models in other areas. IT investment units have much greater potential of creating synergistic values between them, compared to other investment units. Our model provides a solution that IT synergy measures are systemically incorporated into the portfolio selection.

### ***Recommendations to Practitioners***

In this section, we present two guidelines to CIOs and practical IT managers. First, firms should make the process of their IT portfolio selection reflect their own risk threshold or risk appetite. As Table 1.6 shows, different perception about risk would produce different solutions. A firm needs to identify its risk threshold at first by considering their cash flows, the amount of capital, and other financial situation. Then, the firm can find the optimal IT portfolio. Since uncertainty about the value of IT projects is unavoidable and each firm has its own risk threshold, IT portfolio selection also should reflect the risk appetite of the firm.

Second, firms need to evaluate IT project in the aggregate level as well as in the individual level. Many firms still prioritize or select IT projects by simple scoring models based on the individual project level analysis. However, by nature of IT, few IT projects have interdependencies with other IT assets or IT projects. An information system often exchange data or share business process and IT resources of an IT project can easily shared by other IT projects. By taking IT synergy into account to IT project selection, firms can increase return or decrease risk from their IT investment.



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## Tables and Figures

**Table 1.1 Summary of techniques used in project selection models**

<b>Techniques</b>	<b>Project Selection Models</b>
Scoring Model	Lucas and Moore (1976); Kenriksen and Traynor (1999)
Goal Programming (Optimization model)	Gabriel et al. (2006); Loch and Kavadias (2002); Ghasemzadeh and Archer (2000); Chu, et al. (1996); Santhanam and Kyparisis (1996); Santhanam and Kyparisis (1995); Lee and Kim (2000); Dickinson et al (2001); Lin and Hsieh (2004)
Financial model	Verhoef (2002); Kersten and Verhoef (2003); Butler et al. (working paper); Asundi and Kazman (2001)
Visual Map	Ghasemzadeh and Archer (2000);

AHP (Analytic Hierarchy Process) or ANP (Analytic Network Process)	Gabriel et al. (2006); Dey (2006); Lee and Kim (2000); Lee and Kim (2001); Muralidhar et al. (1990)
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**Table 1.2 A sample form of a project evaluation**

	Probability Distribution	0.25 ( ~10 <sup>th</sup> percentile)	0.25 ( ~35 <sup>th</sup> percentile)	0.25 ( ~65 <sup>th</sup> percentile)	0.25 ( ~90 <sup>th</sup> percentile)	Expected Value
Project A	Benefit	\$100K	\$200K	\$300K	\$400K	\$250K
	Cost	\$50K	\$100K	\$150K	\$200K	\$125K
Project B	Benefit	...	...	...	...	...
	Cost	...	...	...	...	...
...	...	...	...	...	...	...

**Table 1.3 A sample form for measuring covariance between two projects**

	I	II	III	IV
$R$	\$100K	\$200K	\$400K	\$300K
$Q$	\$200K	\$100K	\$400K	\$500K
$r - r'$	-\$150K	-\$50K	\$150K	\$50K
$q - q'$	-\$100K	-\$200K	\$100K	\$200K
$(r - r')*(q - q')$	15B	10B	15B	10B

**Table 1.4 IT Porject data**

Project	Value (Billion \$)	Cost (Billion \$)	Value standard deviation (Billion \$)	Cost standard deviation (Billion \$)
1	11.1	5.1	3	0.5
2	11.8	3.9	5	1
3	14.2	5.3	4.24	0.5
4	10.5	4.2	5.2	1.5
5	6.1	2.4	3.64	0.5
6	4.1	2.6	1.5	0.1
7	2.4	1.4	0.7	0.1
8	8.2	4.2	2	0.4
9	7.2	3.1	1.56	0.3

**Table 1.5 IT Project interdependencies**

Interdependent projects	Value Synergy	Cost synergy	Value covariance	Cost covariance
3, 5	\$ 2 M	-	3.6	-
1, 9	\$ 4 M	- \$ 0.3 M	2.5	-
2, 4	-	- \$ 0.3 M	-	0.4
5, 7	-	-	-	- 0.14
...				

**Table 1.6 Solutions of IT Portfolio Optimization Model with different values of  $v_0$ . (The number in the first row indicate Projects and 1 means “selected” and 0 means “not selected”).**

$v_0$	Return	Risk	1	2	3	4	5	6	7	8	9
4	3.89	24.7	1	0	0	0	0	1	1	0	1
6	5.24	41.9	1	0	0	0	1	1	1	1	1
7	6.27	50.8	1	0	1	0	1	1	1	1	1
8	7.86	53.3	1	0	1	1	1	0	1	0	1
9	8.69	54.3	0	1	1	1	1	1	1	0	0
10	9.36	55.1	1	1	1	1	1	0	0	0	0

**Table 1.7 Estimated benefits and super-additive value synergy for four scenarios**

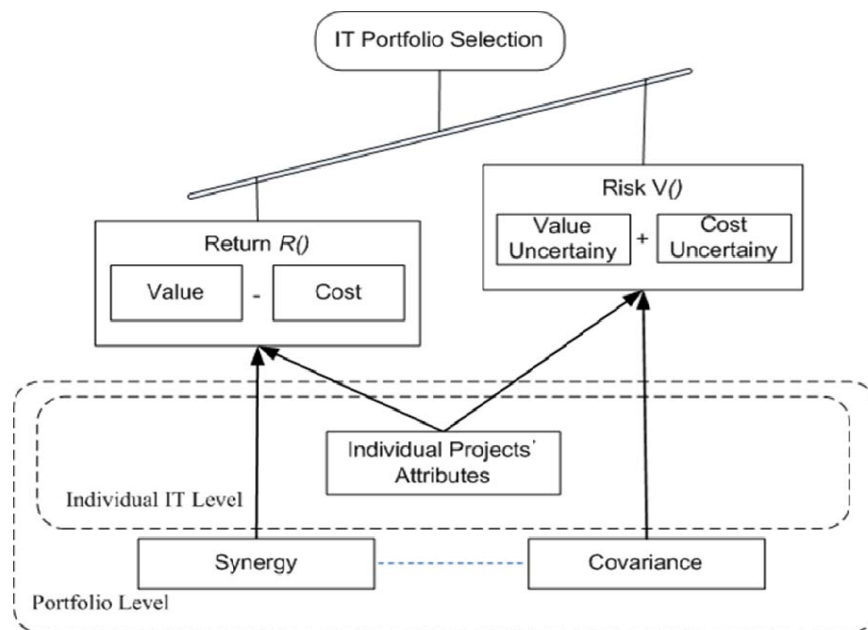
Scenario	Probability	Benefit of CRM project	Benefit of SCM project	Super-additive Value Synergy (in case of the same vendor)
I	0.25	\$100 M	\$50 M	\$10 M
II	0.25	\$30 M	\$200 M	\$5 M
III	0.25	\$30 M	\$50 M	\$0
VI	0.25	\$100 M	\$200 M	\$30 M

**Table 1.8 Estimated costs and super-additive value synergy for four scenarios**

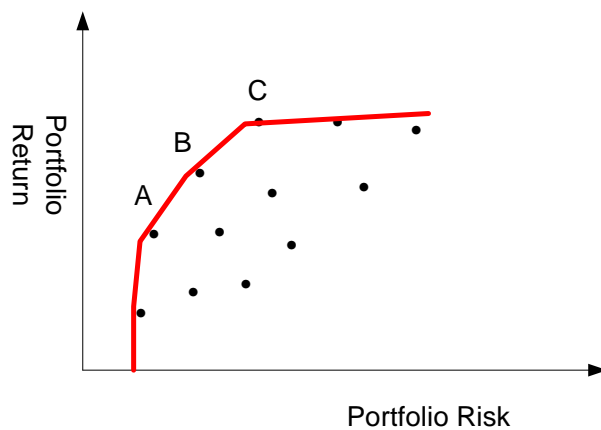
Scenario	Probability	Cost of CRM project	Cost of SCM project	Sub-additive cost Synergy (in case of the same vendor)
A	0.25	50	80	10
B	0.25	40	100	5
C	0.25	40	80	0
D	0.25	50	100	20

**Table 1.9 Comparison of utilities when the firm purchase SCM and CRM from the same vendor and when from different vendors**

Risk Tolerance (T)	Same Vendor	Different vendors	p-value (t-test)
100	-4.59	6.32	0.000141
300	49.32	33.78	4.03E-11
500	62.64	41.38	4.69E-13



**Figure 1.1 IT Portfolio Selection Framework**



**Figure 1.2 Efficient frontier for IT project portfolio**



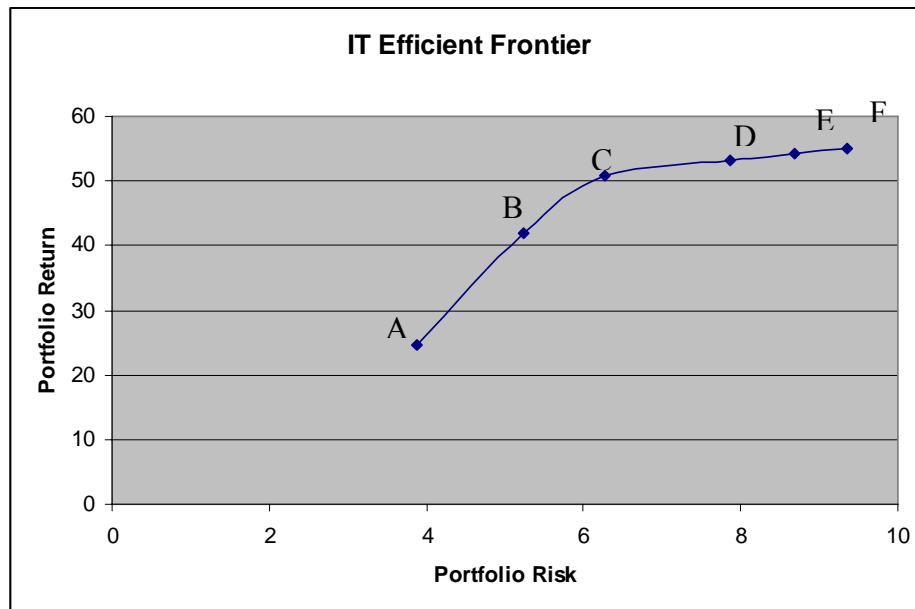


Figure 1.3 IT Portfolio Maps showing IT Portfolio spaces and Efficient Frontiers

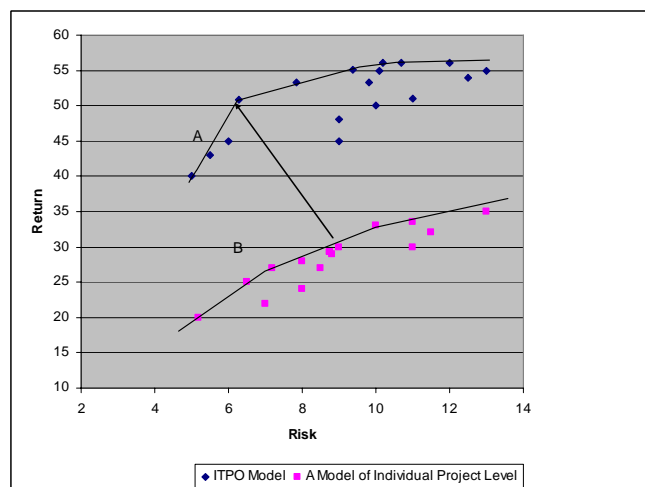
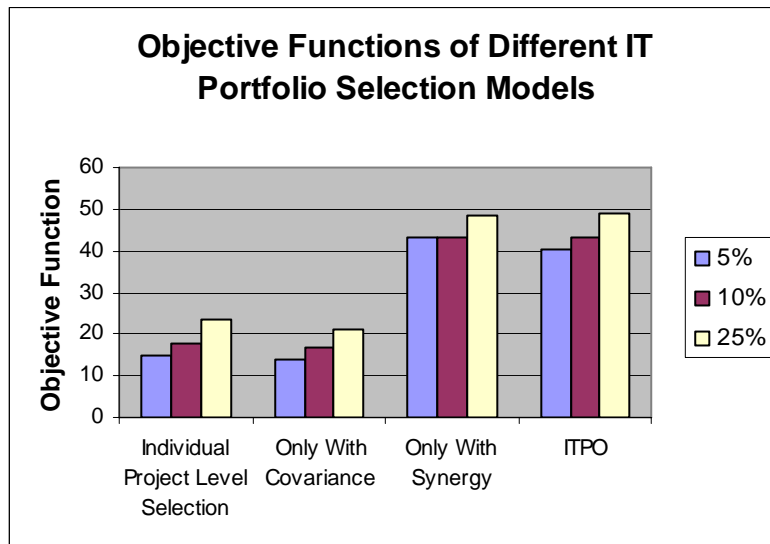


Figure 1.4 Portfolio Selection by ITPO model vs portfolio selection by the alternative model



**Figure 1.5 Results of IT portfolio selections from different IT portfolio selection models**

## **CHAPTER 2. THE IMPACT OF SYNERGY ON IT PORTFOLIO SELECTION**

### **1. Introduction**

It is important for financial investors to know about Markowitz's portfolio selection theory because it proposes that rational investors will diversify their investment to achieve an optimal portfolio. This theory enables investors to reduce the portfolio risk while expecting the same portfolio return (Markowitz 1952). To answer the question of why firms should manage their IT investments as a portfolio, this study shows how rational firms can use IT synergy to optimize their IT portfolio.

IT investments in a firm have continued to increase. An estimated 50% of U.S. capital investment is for IT (Lucas 2005, p. 113). According to our survey of chief information officers (CIOs) in several Fortune 100 firms, the annual IT spending ranges from hundreds of millions of dollars to more than one billion dollars. Along with this trend of growing IT investment, the impact of strategic IT investment on firm performance has become increasingly significant. However, few widely accepted methodologies have been proposed that CIO-level IT managers can use to optimize their IT investment; thus, in this paper we develop a methodological framework for IT portfolio selection in response to the IT investment allocation problem and propose how IT synergy can be used to optimize the IT portfolio.

Weill and Vitale (2002) define the IT portfolio of a firm as “its total investment in computing and communication technology.” Jeffery and Leliveld (2004) define IT portfolio management as “managing IT as a portfolio of assets similar to a financial portfolio and striving to improve the performance of the portfolio by balancing risk and return.” Maizlish and Handler (2005, p. 22) classify the IT portfolio management problem into three different levels: the IT discovery portfolio, the IT project portfolio, and the IT asset portfolio. The IT portfolio may include the IT infrastructure, IT applications, and other IT initiatives that are enabled by IT, such as business process outsourcing and off-shoring, automation, integration, disintegration, or restructuring of business units. CIOs in different firms would have different levels of IT budget allocation problems. Some CIOs of firms may have to allocate the total IT budget to IT organizations within individual functional departments, such as the marketing department or the operations department. Other CIOs in multibusiness firms may have to allocate the IT investment to different business units. The decision unit in our study can be any type of IT investment units, but our main focus is on the allocation problem for which CIOs or senior IT managers are responsible.

We argue that the great potential for synergy enhancement between IT resources differentiates IT portfolio selection from financial portfolio selection. Holding multiple financial products does not create additional return, whereas holding multiple IT units may enable a firm to earn additional returns. This means the return of financial portfolio is a linear function of the returns of individuals. However, the IT portfolio return can be given by a non-linear function due to the synergy, which motivates us to develop IT portfolio selection models.

Many IT organizations have been facing the decision problems associated with synergy enhancement between IT investment units. For instance, integration using EAI (Enterprise Application Integration) software has been regarded as a solution to achieve synergetic values from an organization's information systems. However, a recent survey<sup>1</sup> (Forrester Research 2004), independent integration vendors have not been growing but are declining since 2001. A possible explanation for the decline is that the integration increases IT portfolio risk as well as IT portfolio return, and, as results, some companies may not want to take risk by investing in system integration.

Tanriverdi and Ruefli (2004) discuss the return/risk relationship in the finance and strategic management literature. In finance, the efficiency of a market implies a positive linear relationship between portfolio return and risk. However, in the strategic management literature, it is assumed that strategic decisions affect the return/risk relationship. Our framework adopts the assumption used in the strategic management literature. We argue that strategic use or enhancement of IT synergy can help firms achieve a superior IT portfolio.

In this paper, we develop a framework for IT portfolio selection by modeling three types of IT synergy. To investigate how IT synergy can be used to achieve an optimal IT portfolio, we examine the effect of IT synergy on a firm's IT portfolio selection process by using the framework. This paper proposes a model of IT portfolio selection that helps decision makers in a firm attain an optimal IT portfolio, particularly through strategic use of IT synergy. We found that firms with a moderate and high risk threshold are likely to

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<sup>1</sup> Rymer, J.R., Gilpin, M. and Vollmer, K. (2004) "Integration Landscape 2005," Forrester Research, Dec. 22.

obtain superior IT portfolios by enhancing IT synergy, whereas firms with low risk threshold may not benefit from IT synergy enhancement.

## **2. Theoretical Background**

### ***2.1. Extending Markowitz's Portfolio Selection Theory***

This paper extends Markowitz's portfolio selection theory to IT portfolio selection problems. Financial theories have been applied in the strategic planning of firms. Meyers (1984) argues that finance theory must be extended to bring financial and strategic analysis together. In Markowitz's portfolio selection theory, an investor's problem is viewed as a problem of balancing return and risk. The main benefit of using Markowitz's portfolio selection theory in financial investment is that an investor can reduce portfolio risk simply by holding multiple securities that are not perfectly correlated (Markowitz 1991).

One of the applications of Markowitz's theory is to use an optimization model to select a portfolio. In the framework of this theory, investors would find an optimal portfolio that lies on the mean-variance efficient frontier, which is the intersection between the set of portfolios with minimum variance and the set of portfolios with maximum return (Kroll et al. 1984). The efficient frontier can be achieved by solving the following optimization problem, which Markowitz addressed as one of the possible programming models based on his portfolio selection theory (Markowitz 1991, pp. 186–187):

$$\text{Maximize } RT \tag{2.1}$$

$$\text{Subject to } RK \leq RK_0$$

$$(\text{other constraints}),$$

where  $RT$  is the expected portfolio return,  $RK$  is the expected portfolio risk, and  $RK_0$  refers to a certain level of risk. In particular, the problem for selection of the securities portfolio can be represented by  $RT = \mathbf{E}'\mathbf{x}$  and  $RK = \mathbf{x}'\mathbf{\Sigma}\mathbf{x}$ , where  $\mathbf{x}$  is a vector of decision variables, the number of stocks, which represents the number of stocks or the dollar amount invested in a financial product;  $\mathbf{E}'$  is a vector that represents the expected return of individual stocks;  $\mathbf{\Sigma}$  is the covariance matrix between securities, and  $RK_0$  refers to the maximum level of risk that the investor is willing to take. In financial portfolio selection, the expected return on individual stocks and the covariance matrix between securities are calculated with historical stock price data.

In financial portfolio selection, Markowitz's theory proposes how rational investors should use diversification to reduce portfolio risk. By extending that theory, we aim to propose how rational firms should use IT synergy to obtain the optimal IT portfolio, where IT synergy affects both portfolio return and portfolio risk. Figure 2.1 and Figure 2.2 compare the framework for Markowitz's portfolio selection with that for IT portfolio selection.

## ***2.2 The Role of Synergy***

Synergy refers to the additional return attained when firms can gain from multiple investment units, which cannot be attained from individual, stand-alone units. Synergy between multiple investment units has been actively discussed in the corporate strategy literature. It has been argued that the gain in wealth can be attributed to the utilization of resources, resulting in different types of synergies (Bradley et al. 1983, Eckbo 1983). IT systems are an enabler of complementary synergy among resources of an organization

(Kim and Mahoney 2006). Economies of scope enable a firm to share or utilize related inputs, which enhance synergy (Teece 1980, Willig 1978). The synergy obtained from diversification has been investigated, particularly in the domain of multibusiness firms (Amihud and Lev 1981, Christensen and Montgomery 1981, Farjoun 1998, Miller 2004, Palepu 1985, Robins and Wiersema 1995, Rumelt 1982, Tanriverdi and Venkatraman 2005). The main concern of prior studies in the corporate strategy literature is whether a corporation should diversify in its businesses. In the corporate strategy literature, synergy enhancement is the outcome of diversification, rather than of the strategic option or a tool of portfolio management.

However, in the domain of IT investment by the firm, synergy enhancement can be a strategic tool for CIOs or IT managers. Information technologies have enormous potential for synergy enhancement. For instance, IT managers are able to enhance the degree of integration between systems with additional costs. A firm is able to increase synergy by integrating multiple information systems and by standardizing data formats and business processes. Thus, the discussion of synergy in this paper has a different aim from that in studies of corporate diversification strategy. Our focus is on the effect of synergy on a manager's decision to achieve an optimal portfolio. The results will provide firms or CIOs with guidelines not only in their decision regarding IT portfolio selection, but also in their planning for IT integration.

For IT resources, two types of synergies have been discussed, sub-additive cost synergies and super-additive value synergies (Tanriverdi 2005). First, sub-additive cost synergies have been explained by the economies of scope that can be attained through



diversification (Panzar and Willing 1981, Teece 1980, Willing 1978). Synergistic economies arise from inputs that are shared by related businesses (Hill et al. 1987). Resource relatedness refers to the use of common resources across units. According to the resource-based view of the firm, the use of common production factors across units creates synergies, which are sub-additive production cost synergies (Farjoun 1998, Robins and Wiersema 1995, Tanriverdi 2006). Second, super-additive value synergies can be derived from Edgeworth complementarities, in which “doing more of one thing increases the returns to do more of another” (Milgrom and Roberts 1995). Resource complementarity is a major source of cross-unit synergy (Tanriverdi and Venkatraman 2005). According to the economic theory of complementarities (Milgrom and Roberts 1995), a set of resources is complementary when the return from a resource varies in its level of return from those of other resources. A complementary set of resources creates super-additive value synergies.

### ***2.3 IT Portfolio Selection***

Investments of a firm in various IT activities are to be managed aggregately and planned centrally because of the large amount firms spend on IT. To our knowledge, McFarlan (1981) was the first to use the term *IT portfolio* to emphasize the issues of risk management in an IT investment. However, it was not until the late 1990s that IT portfolio management gained the full attention of practitioners and researchers, mainly because of the radical increase in IT investment in firms. Although multiple levels of IT portfolio management (Maizlish and Handler 2005) exist, most previous studies have focused on the problem of IT project portfolio selection. Several studies of IT project portfolio selection have stressed project interdependencies among IT projects and have proposed a mode to

overcome the challenges presented by classical models of project selection and the proposed models of IT project selection (Dickinson et al. 1999, Lee and Kim 2000, Santhanam and Kyparisis 1995). However, those studies address the impact of IT synergy only on portfolio return, not on portfolio risk. This paper studies the impact of IT synergy on portfolio risk as well as portfolio return, and proposes how rational firms will use IT synergy to optimize their IT portfolio.

The research problem in our study is IT investment allocation, instead of IT project selection. IT investment allocation is a decision that can be completed prior to IT project selection to align the IT investment with the firm's strategy. The top-down approach can enable firms to spend their IT budget according to their strategic priorities. Among the CIOs we interviewed, CIOs in multibusiness firms have to select IT projects or initiatives out of hundreds of proposals submitted from multiple IT business units. According to a CIO, all business units try to obtain the maximum IT budget so they can implement as many of their proposed IT projects as possible. However, because of limits on the IT budget, the CIO needs to allocate the investment, depending on the properties of the IT units. However, discussion is lacking on methodologies for IT investment allocation.

#### ***2.4 Portfolio Risk***

Mixed results have been reported in empirical studies on the relationship between IT investments and firm performance. A possible reason for the mixed results is that most studies ignore risk but measure performance in terms of return (Tanriverdi and Ruefli 2004). Because both return and risk are major dimensions of the performance of an investment (Bettis and Mahajan 1985), this study develops a framework for IT portfolio

selection in which both return and risk are conceptualized as subobjectives. In finance, portfolio risk is defined as the standard deviation of the portfolio's return (Markowitz 1952). In the management literature, four definitions of risk have been used: (1) size of loss, (2) probability, (3) standard deviation (variance) of returns, and (4) lack of information (Tanriverdi and Ruefli 2004). Among those definitions, we use the third definition, the standard deviation of portfolio return, because it has the strongest mathematical foundation compared with other definitions, and we use an analytical approach in this paper.

### **3. Development of IT Synergy Models**

Similar to the general concept of synergy, IT synergy refers to the additional return that a firm can achieve from multiple IT investment units that cannot be obtained from individual, stand-alone units. We argue that IT resources have unique characteristics that bring great potential for creating synergy compared with non-IT resources. In this section, we justify this argument by discussing why IT resources are more significant sources of synergy than non-IT ones. This discussion will add importance to the role of IT synergy in IT portfolio management.

#### ***3.1 Characteristics of IT Resources***

We address three unique characteristics of IT resources that are related to the great potential for synergy enhancement. First, IT resources can be used remotely. Most IT services are provided and shared through networks, and geographic constraints in using resources are minimized. Computer machines and software programs may not need to be moved or reinstalled to be used in a specific place, and developers can work remotely through networks. IT applications can be executed with few restrictions caused by end

users' location. This feature makes IT resources much more sharable between different IT investment units and creates greater synergy.

Second, IT resources can be used by multiple users simultaneously. As long as the traffic limit is not exceeded, many IT resources can be used by many individuals whenever they are needed. Most non-IT resources are rarely shared simultaneously, and this would require users to schedule and reserve in advance, which could constrain the sharing of resources. By being free from this constraint, IT resources can enhance synergy to a greater degree than non-IT resources.

Third, the integration of heterogeneous IT systems enables firms to share business processes and exchange data, which enhances complementarities between IT components. The data provided by an information system makes other systems more valuable. Integrated business processes between multiple information systems can create additional sets of data. Thus, we can say that the value of an IT application affects the value of another IT application. The scope of IT integration is very wide because IT functions are applicable across a wide range of businesses and industries (Tanriverdi 2006). IT human resources and IT professionals are not limited to any specific industry and can move across firms (Agarwal and Ferrat 2002), and IT vendor relationships are also not specific to any particular industry (Feeny and Willcocks 1998).

### ***3.2 The Uncertainty of IT Resources***

The resources of a firm can be anything that is thought of as a strength or weakness of the given firm (Wernerfelt 1984). According to the resource-based view of the firm, the resources of a firm enable the firm to achieve a competitive advantage and drive it toward

superior long-term performance (Barney 1991, Penrose 1959, Wernerfelt 1984). Using the criteria for strategic resources in the resource-based view (valuable, rare, inimitable, and nonsubstitutable, Barney 1991), we can argue that one main role of the CIO of the firm is to develop strategic IT resources from the IT investment by making the IT resources valuable, rare, inimitable, and nonsubstitutable. When the IT resources of the firm fit well with the unique needs of the organization, the firm is able to achieve the maximum value from its IT resources.

### ***3.3 Modeling Three Types of IT Synergy***

Figure 2.4 illustrates our model of the two-unit IT portfolio, in which IT synergy can be enhanced, compared with an IT portfolio in which synergy is not enhanced, as described in Figure 2.3. As discussed earlier, by viewing IT units aggregately, a firm is able to take synergies into consideration in its IT portfolio selection. We classify IT synergies into three types: sub-additive IT synergies (*c*-type synergies); one-way super-additive IT synergies (*ov*-type synergies); and two-way super-additive IT synergies (*tv*-type synergies). Table 2.1 summarizes the three types.

To develop models of the three types of IT synergies, we use the following notations:

- $x_i$ : the proportion of IT investment unit  $i$  out of the total IT investment ( $i = 1, 2$ ;  $0 < x_1, x_2 < 1$ ;  $x_1 + x_2 = 1$ )
- $V_i$ : the return on investment (ROI) of IT investment unit  $i$  when the two IT units are evaluated without considering any synergy; we assume  $V_i \sim N(r_i, \sigma_i)$ .
- $V$ : the portfolio return

- $\alpha_{ij}$ : the maximum percentage of IT resources that IT investment units  $i$  and  $j$  can share out of the sum of IT resources required by the two investments ( $\alpha_{ij} = \alpha_{ji} > 0$ )
- $\beta_{ij}$ : the marginal increase (decrease) of the ROI of IT investment unit  $j$  over the marginal increase (decrease) of the value of IT investment  $i$  in one-way super-additive value synergy ( $\beta_{ij} > 0$ )
- $\delta_{ij}$ : the marginal increase (decrease) of the ROI of IT investment unit  $j$  over the marginal increase (decrease) of the value of IT investment  $i$  in two-way super-additive value synergy in two-way super-additive value synergy ( $\delta_{ij}, \delta_{ji} > 0$ )

### 3.3.1 Sub-additive Cost IT Synergy

Sub-additive cost IT synergy ( $c$ -type synergy) refers to additional input savings in IT investment when there is sharing of commercial IT resources between two IT units. Examples of  $c$ -type synergy can easily be found. Hardware, software, network systems, IT human resources, and other IT resources can be shared across different business units or functional groups.

In our model, we assume that the maximum percentage of IT resources shared between two IT investment units can be estimated by IT experts in the firm. The additional portfolio return will be the amount that the firm can save by sharing existing IT resources. The amount will be  $\alpha_{12}x_1x_2$ . The maximum degree of share will be increases as  $x_1$  increases and  $x_2$  increases. We assume the return of IT investment unit  $i$ ,  $V_i$ , is normally distributed with  $V_i \sim N(r_i, \sigma_i)$ . Then, when  $c$ -type synergy exists and other types of IT synergy do not exist, the expected portfolio return,  $RT$ , will be:

$$RT = r_1 x_1 + r_2 x_2 + \alpha_{12}x_1x_2 \quad (2.2)$$

We define portfolio risk as the standard deviation of portfolio return, as defined in the financial literature. The sub-additive cost IT synergy does not affect portfolio risk because the additional return is not associated with any ROI terms that are uncertain. Thus, the variance in portfolio return with *c*-type synergy is the same as the variance in portfolio return without synergy. The portfolio risk,  $RK$ , will be

$$\begin{aligned}
 RK &= [Var(V_1 x_1 + V_2 x_2 + \alpha_{12} x_1 x_2)]^{1/2} \\
 &= [Var(V_1 x_1 + V_2 x_2)]^{1/2} \\
 &= [\sigma_1^2 x_1^2 + \sigma_2^2 x_2^2 + 2\sigma_1 \sigma_2 \rho x_1 x_2]^{1/2}
 \end{aligned} \tag{2.3}$$

### 3.3.2 One-Way Super-additive Value IT Synergy

Super-additive value synergy refers to the additional return created by the complementary relationship between two investment units. The condition of super-additive value synergy is  $Value(A + B) > Value(A) + Value(B)$  (Davis and Thomas 1993). In this study, we define one-way super-additive IT synergy and two-way super-additive IT synergy as an extension of the concept of super-additive value synergy.

One-way super-additive IT synergy (*ov*-type synergy) refers to the one-directional complementarities in a two-unit IT portfolio. It occurs when, between two IT investment units, the intrinsic value of the first IT investment unit significantly affects the value of the second unit but is rarely affected by the value of the second unit. We posit that the complementarities in *ov*-type synergy are different from the complementarities in which both units are mutually beneficial. The relationship between IT infrastructure and other IT applications can be a good example of asymmetric complementarities. Zhu (2004) explains that the effect of IT infrastructure and e-commerce capability with complementarities. The performance of most IT applications is influenced by the performance of the hardware and

networks. As the performance of the hardware and networks increases, the productivity of IT applications will increase. In an e-commerce firm of which business performance is determined by the performance of its web application, the IT infrastructure is positively related to the value of IT in the business unit (Zhu 2004).

We assume that, in the relationship between IT investment unit  $i$  and IT investment unit  $j$  ( $i, j = 1, 2, i \neq j$ ), the marginal increase (decrease) of the ROI of IT investment unit  $j$  over the marginal increase (decrease) of the value of IT investment  $i$ ,  $\beta_{ij}$ , can be estimated in the range of  $x_i$  and  $x_j$  specified by the firm. We assume  $\beta_{ij} \geq 0$  because IT managers would not enhance synergy between the two IT units when  $\beta_{ij} < 0$ . When IT investment unit 1 has *ov*-type synergy on IT unit 2, the firm will obtain the additional return  $\beta_{12}(V_1x_1)x_2$ .

Then, when *ov*-type synergy exists without any other types of IT synergies, the expected portfolio return on IT investment units 1 and 2 will be

$$RT = r_1x_1 + r_2x_2 + \beta_{12}(r_1x_1)x_2. \quad (2.4)$$

In calculating portfolio risk, we assume that the firm can collect information about the correlation between the ROI of the two investment units,  $\rho_{12}$ , and the standard deviation of the ROIs,  $\sigma_1$  and  $\sigma_2$ . Then, when super-additive value synergy exists, the portfolio risk will be

$$\begin{aligned} RK &= [Var(V_1x_1 + V_2x_2 + \beta_{12}(V_1x_1)x_2)]^{1/2} \\ &= [\sigma_1^2x_1^2(1 + \beta x_2)^2 + \sigma_2^2x_2^2 + 2\sigma_1\sigma_2\rho x_1x_2(1 + \beta x_2)]^{1/2} \end{aligned} \quad (2.5)$$

### 3.3.3 The Two-Way Super-additive Value IT Synergy



Two-way super-additive value IT synergy (*tv*-type synergy) refers to symmetric complementarities. It occurs when the two IT units are mutually beneficial. This can be achieved when more than one enterprise system shares data and business processes. For example, marketing systems and new product development systems of a firm can exchange data about customers and their preferences for quality attributes of a product. This data exchange can help the marketing systems do marketing research and find customers, and can help new product development systems in designing new products.

We assume that, in the relationship between IT investment unit  $i$  and unit  $j$  ( $i, j = 1, 2, i \neq j$ ), the marginal increase (decrease) of the ROI of IT investment unit  $j$  over the marginal increase (decrease) of the value of IT investment  $i$ ,  $\delta_{ij}$ , can be estimated in the range of  $x_i$  and  $x_j$  specified by the firm. With this assumption, we formulate the additional return from *tv*-type synergy as follows: The additional portfolio return will be the amount of additional value that the firm can attain, and the amount will be  $(\delta_{12}V_1 + \delta_{21}V_2)x_1x_2$ . Then, when *tv*-type synergy exists without other types of IT synergies, the expected portfolio return will be

$$RT = r_1 x_1 + r_2 x_2 + (\delta_{12}r_1 + \delta_{21}r_2)x_1x_2. \quad (2.6)$$

This type of IT synergy appears to change the portfolio return because the additional term includes the ROIs that have uncertainty:

$$\begin{aligned} RK &= [Var(V_1 x_1 + V_2 x_2 + (\delta_{12}V_1 + \delta_{21}V_2)x_1x_2)]^{1/2} \\ &= [\sigma_1^2 x_1^2 (1 + \delta_{12}x_2)^2 + \sigma_2^2 x_2^2 (1 + \delta_{21}x_1)^2 + 2\sigma_1 \sigma_2 \rho x_1 x_2 (1 + \delta_{21}x_1)(1 + \delta_{12}x_2)]^{1/2}. \end{aligned} \quad (2.7)$$

#### 4. IT Portfolio Selection Model

We intend to solve problems of IT investment allocation that CIOs or senior IT managers in large firms would often face. In developing IT portfolio selection models, we apply Markowitz's mean-variance efficient frontier. This approach is used in this study because we use analytical methods and this approach has a stronger theoretical and mathematical basis compared alternative approaches. The efficient frontier is a visual presentation of the balance between portfolio return and risk. We believe that it is a useful tool for decision makers because the IT portfolio is an investment for them, and every investment can be viewed as a problem of balancing return and risk. Similar to the efficient frontier for securities portfolio selection (Kroll et al. 1984), the IT efficient frontier can be defined as the set of portfolios with minimum variance and with maximum return. However, we extend the original Markowitz efficient frontier by incorporating the construct of IT synergy. The difference between the IT efficient frontier and Markowitz's mean-variance efficient frontier is that it is synergy enhancement, as well as diversification, that shifts the efficient frontier of an IT investment.

The objective of the firm in the problem of IT investment allocation is to balance two sub-objectives: to maximize portfolio return and to minimize portfolio risk. Portfolio return is influenced by the return from individual IT investment units and synergies. These synergies include *c*-, *ov*-, and *tv*-type synergies. We assume that *ov*-type synergy and *tv*-type synergy between the two IT units are exclusive. In our model, we use synergy measured only between two units because, in practice, it is very difficult to measure added

value when more than three IT units interact. The portfolio return,  $RT$ , can be represented as

$$RT = RT(\text{expected returns from individual IT units, synergies}).$$

The risk of an IT portfolio can be defined as the volatility of the return, which, conceptually, refers to the degree of uncertainty of the return and, statistically, refers to the standard variation of the return. Thus, the portfolio risk,  $RK$ , can be represented as

$$RK = \{Var [RT(\text{expected returns from individual IT units, synergies})]\}^{1/2}.$$

For example, the IT efficient frontier consists of two IT investment units, as illustrated in Figure 2.4, and can be plotted with the following formulas:

$$RT = r_1 x_1 + r_2 x_2 + \alpha_{12} x_1 x_2 + \beta_{12} (r_1 x_1) x_2 + (\delta_{12} r_1 + \delta_{21} r_2) x_1 x_2 \quad (2.8)$$

$$RK = [Var(V_1 x_1 + V_2 x_2 + \alpha_{12} x_1 x_2 + \beta_{12} (V_1 x_1) x_2 + (\delta_{12} V_1 + \delta_{21} V_2) x_1 x_2)]^{1/2}.$$

The decision variable in the model is the proportion of investment for each IT investment unit. The IT investment unit can be any level that CIOs or senior IT managers would allocate to their IT budget. The amount of dollars in each IT investment unit is normalized, and  $x_i$  refers to the ratio of the amount of dollars to the total IT investment. The range of  $x_i$  will be from zero to one.

Constraints in the IT portfolio optimization model should address the unique characteristics of the firm or the IT organization of the firm. They may include budget constraints, logical constraints, positioning constraints (Liesio et al. 2008), threshold constraints (Kleinmuntz 2007).

The optimization problem of balancing return and risk can be formulated by the three optimization models, which produce an identical efficient frontier. The first model is

to maximize portfolio return with the constraints of portfolio risk. The second model is to minimize portfolio risk subject to a certain level of portfolio return. The third model can have an objective function of the linear combination of return and risk.

Model 1: (2.9)

*Maximize*  $RT$

*Subject to*  $RK \leq RK_0$

(other constraints),

where  $RK_0$  refers to the maximum level of portfolio risk that the firm can tolerate.

Model 2: (2.10)

*Minimize*  $RK$

*Subject to*  $RT \geq RT_0$

(other constraints),

where  $RT_0$  refers to the minimum level of portfolio return that the firm must achieve.

Model 3: (2.11)

*Maximize*  $RT + w(RK - RK_0)$

*Subject to* (other constraints),

where  $w$  is the parameter that represents the weight attached to portfolio risk compared with portfolio return.

The dual-criterion linear programming in Model 3 can be theoretically explained by Lagrange relaxation of the optimization problem of maximizing portfolio return with the constraint of not taking a certain level of risk. Then,  $w$  would be a Lagrange multiplier that represents the shadow price of the risk constraints. If we let  $L = RT + w(RK - RK_0)$ ,

$\partial RT / \partial RK = w$  because  $\partial L / \partial RK = w$  and  $\partial L / \partial RT = 1$ . Therefore, the Lagrange multiplier  $w$  refers to the marginal increase in portfolio return over a unit-increase in portfolio risk at a given portfolio risk.

In an IT portfolio that consists of  $n$  IT investment units, the portfolio return and the portfolio risk are defined as

$$RT = \sum_{i=1}^n r_i x_i + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \alpha_{ij} x_i x_j + \sum_{i=1}^n \sum_{j=1}^n \beta_{ij} (r_i x_i) x_j + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n (\delta_{ij} r_i + \delta_{ji} r_j) x_i x_j \quad (2.12)$$

$$RK = [Var(RT)]^{1/2}.$$

## 5. Illustration of Examples

In this section, we illustrate an example of IT portfolio selection that CIOs or senior IT managers in a firm might face, and discuss the results. The aim of this section is to show that our framework is useful to the firm in the decision-making process of IT portfolio selection. We assume a firm has an allocation problem for three IT investment units: one is the IT investment for business unit 1, another is the IT investment for business unit 2, and the third is the IT infrastructure. The IT infrastructure includes hardware, networks, and software, which are presumably shared by the two business units. The IT investment for business unit 1 is characterized as low return and low risk, and the IT investment for business unit 2 as high return and high risk. We also assume that the investment in IT infrastructure has *ov*-type synergy on the IT value of both business units and that potential *c*-type synergy exists between the IT investments for the two business units.

Based on those assumptions, we use the IT portfolio data reported in Table 2.2. Using these data, we can formulate the portfolio return and portfolio risk as follows.

$$RT = \frac{2.2x_1 + 4x_2 + 1.3x_3 + \alpha_{31}(1.3x_3)x_1 + \alpha_{32}(1.3x_3)x_2 + \beta_{12}\{x_1x_2 / (x_1 + x_2)\}}{(2.2\delta_{12} + 4\delta_{21})x_1x_2} \quad (2.13)$$

$$RK = [Var(V)]^{1/2}.$$

Here,  $x_1$ ,  $x_2$ , and  $x_3$  are the decision variables, that is, the proportion of the investment in IT for business unit 1, business unit 2, and the IT infrastructure, respectively. Using the portfolio data described in Table 2.2 and Equation (2.13), we can obtain the solution shown in Table 2.3.

The values in the first column in Table 2.3 indicate the risk threshold of the firm, whereas the values in the second, third, and fourth columns are the proportions of IT investment for business unit 1, business unit 2, and the IT infrastructure, respectively, at a corresponding risk threshold. For example, if the risk threshold of a firm is 1.24, then the optimal IT portfolio will be 43.0, 41.1, and 16.0% of the total IT investment for business unit 1, business unit 2, and the IT infrastructure, respectively.

Figure 2.5 shows the solutions for the IT portfolio selection problem at different levels of risk threshold with variation of the firm's risk threshold. Because the IT investment for business unit 2 is characterized as high return and high risk, the  $x_2$  increases as the firm takes a greater risk in its portfolio selection. The  $x_1$  decreases as the risk threshold of the firm increases because the expected return and risk of the firm are lower than the return and risk for IT for business unit 2. The  $x_3$  gradually increases as the risk threshold decreases until the risk threshold becomes greater than 1.7. The results show that a firm will select different IT portfolios depending on its risk threshold.

Next, we examine how IT synergy affects IT portfolio selection. We run the optimization models with  $\alpha_{12} = \alpha_{21} = 0.1$  and  $\beta_{31} = 0.2, \beta_{32} = 0.2$ , instead of the values of those parameters in Table 2.2. In this portfolio, there is a smaller degree of *c*-type synergy between the IT of business units 1 and 2, and the IT infrastructure has a smaller degree of *ov*-type synergy on the other two IT units. Figure 2.6 shows different sets of solutions from those shown in Figure 2.5. This result implies that synergy affects the optimal IT portfolio, and that selecting an IT portfolio without measuring IT synergy will cause the firm to have a suboptimal IT portfolio.

In addition, we ran the model of IT portfolio optimization with *tv*-type synergy ( $\delta_{12} = \delta_{21} = 0.3$ ), instead of *c*-type synergy ( $\alpha_{12} = \alpha_{21} = 0$ ), between the first two IT investment units. From Figure 2.7 we found that *tv*-type synergy between IT investment units 1 and 2 caused a greater amount of IT investment to be allocated to the first two IT investment units and a smaller amount of the IT budget to be allocated to the IT infrastructure.

In conclusion, the results of this example indicate that firms would have different optimal IT portfolios depending on their risk threshold or risk appetite, and an enhancement of IT synergy might cause them to obtain different solutions. In the next section, we investigate further how these three different types of IT synergy influence IT portfolio selection differently when computational studies are used.

## **6. The Effect of IT Synergy on IT Portfolio Selection: Computational Study**

This section aims to examine the effects of the three types of IT synergies on a firm's portfolio selection, using an IT portfolio for two investment units as described in Figure 2.4. Firms can raise several questions: Do synergy enhancement always offer better

portfolios? If not, under what conditions do synergies enable firms to have superior portfolios or inferior ones? By observing changes in the efficient frontier of the firm, we intend to discuss these questions.

Because our model uses data on synergies and correlations measured between two IT units, rather than data measured among more than three IT units, analysis for the two-unit portfolio can be a base of the efficient set for many IT units. The main use of the efficient frontier is to identify feasible portfolios and the efficient portfolio set. We can obtain feasible portfolios and an efficient frontier for many units by combining feasible areas plotted by pairs of IT units, pairs of an IT unit and an aggregate IT unit, or pairs of aggregate IT units. We take into consideration the following assumptions in a firm's problem of IT investment allocation in this section: (1) the firm needs to allocate an IT budget for the two IT investment units; and (2) the first IT investment unit is characterized as low return and low risk, and the second unit return and high risk.

The computational study requires specification of project data. We use the data given in Table 2.4 that we assume the firm collected for the two IT investment units. The ROIs are estimated for four scenarios (scenarios I, II, III, and IV), the probabilities of which are 25%. Using the data in Table 2.4, we can calculate the expected ROI of unit 1 (2), the expected ROI of unit 2 (3.5), the standard variation of the ROI of unit 1 (0.71), the standard variation of the ROI of unit 2 (1.27), and the covariance (0.58).

### ***6.1 The Effect of Sub-additive Value IT Synergy***

Saving costs by sharing IT resources is often eligible when common IT resources are used in two IT investment units. Depending on the technologies and resources of the



two IT units, some pairs can be characterized as having a high  $\alpha$ , which means a high degree of IT resource sharing, and other pairs can be characterized as having a low  $\alpha$ . Figure 2.8 illustrates the change in the efficient frontier as the  $c$ -type synergy of the two IT investments increases. We observed the shift of the efficient frontier with variation of the coefficient  $\alpha_{12}$ , from zero to one with 0.1 increments. It appears that  $c$ -type synergy is always beneficial because it does not increase the portfolio risk but increases the portfolio return if the coordination cost for enhancing  $c$ -type synergy is not significant.

According to the results shown in Figure 2.8, in the two-unit portfolio, the firm can benefit from greater sharing and cost savings as its investment is more diversified. Because one unit is a high-risk IT investment and the other unit is a low-risk IT investment, a diversified portfolio would be one solution for our optimization model for firms with moderate risk threshold. Thus, firms with moderate risk threshold can benefit more from the enhancement of  $c$ -type synergy. This result implies that the greater degree of  $c$ -type synergy enhancement a firm has, the more beneficial will be to the firm as long as the firm is able to manage to coordinate and provide the sharing. This can be explained by our observation from the survey with practitioners. Most of them desire to increase IT resources sharing. A company recently organized an independent IT infrastructure division to maximize sharing of IT resources across the company. Their main concern in enhancing  $c$ -type synergy is whether the independent IT infrastructure division can manage effectively coordination costs.

## 6.2 The Effect of One-Way Super-additive Value IT Synergy

In Figure 2.9, we compared the efficient frontiers that a firm has with different levels of *ov*-type synergy between the two IT investment units. The figure illustrates the shift of the efficient frontier as the level of *ov*-type synergy increases, in a case in which the low-return and low-risk IT investment unit has a one-way complementary relationship with the high-return and high-risk IT investment unit. The dashed line represents the efficient frontier with higher levels of *ov*-type synergy. There is a point at which the two efficient frontiers cross. According to this result, firms whose risk threshold is higher than the critical point obtain superior portfolios, and firms whose risk threshold is lower than the critical point have inferior portfolios. We found that the point moved toward a point of higher risk as the correlation between the two units decreased. Our result is based on the experiments with variation of the coefficient  $\beta$ , from zero to 0.5 with 0.05 increments. This implies that the impact of *ov*-type synergy on portfolio risk becomes greater as covariance between the two units increases. To generalize our findings, we provide conditions where *ov*-type synergy is beneficial to the firm with the following propositions.

*Proposition 1A. When  $\beta < \frac{r_2 - r_1}{r_1}$ , the firm with high risk tolerance benefits from*

*the enhancement of one-way super-additive value IT synergy if  $\frac{r_1 / \sigma_1}{r_2 / \sigma_2} > \rho$ .*

*Proposition 1B. When  $\beta < \frac{r_2 - r_1}{r_1}$ , the firm with low risk tolerance cannot benefit*

*from the enhancement of one-way super-additive value IT synergy if  $\frac{r_1 / \sigma_1}{r_2 / \sigma_2} < \frac{1}{\rho}$ .*

Proofs are provided in Appendix B. With consideration of the nature of investment, the return-risk ratio between  $r_1 / \sigma_1$  and  $r_2 / \sigma_2$  will be not too far from one when the two units are considered as candidates. Because  $\rho$  is less than 1, and then  $1 / \rho$  will be greater than one if the correlation is positive. Then, the firm with low risk tolerance is more likely not to benefit from the enhancement of one-way super-additive value synergy if the degree of the synergy is small enough. On the contrary, because the risk of an investment increases as the return of the investment increases in general, the ratio between  $r_1 / \sigma_1$  and  $r_2 / \sigma_2$  is likely to be greater than one. Then, it is most likely that the firm with high risk tolerance benefits from the enhancement of one-way super-additive value synergy

Interestingly, the result implies that synergy is not always beneficial to a firm, which is different from conventional thinking about synergy. Firms whose risk threshold is lower than a certain level appear to have inferior IT portfolios. That may happen when the increase in portfolio risk is more significant than the increase in portfolio return by the enhancement of IT synergy. To the contrary, firms that prefer taking relatively high risks or that have a high risk threshold are likely to benefit from the *ov*-type IT synergy.

### ***6.3 The Effect of Two-Way Super-additive value IT Synergy***

We consider symmetric two-way super-additive value synergy in this analysis, which means that we assume  $\delta = \delta_{12} = \delta_{21}$  in our synergy model. From the analytical solution of the IT portfolio selection model, we found that if  $\delta$  is small enough, firms may have an inferior portfolio after they enhance the two-way super-additive value synergy depending on their risk threshold and portfolio properties.

Figure 2.10 illustrates the effect of  $tv$ -type synergy on the IT portfolio selection of the firm. We observed changes in the efficient frontier with variation of the coefficient  $\delta$ , from zero to 0.3 with 0.03 increments in the case of portfolio problem described in Table 2.4. The effect of  $tv$ -type synergy appears to be similar to that of  $ov$ -type synergy in that the two efficient frontiers cross at a point of low portfolio risk. Firms with a higher risk threshold than the critical point have superior portfolios and firms with a lower risk threshold than the critical point have inferior portfolios.

We found that  $tv$ -type synergy would have a greater impact on the firms that prefer taking higher risks than on the firms with a low risk threshold. Compared with Figure 2.9, the dashed line in Figure 2.10 is skewed more to the right and upward. This implies that  $tv$ -type synergy is more beneficial to firms with a high risk threshold. In contrast,  $ov$ -type synergy appears to be more beneficial to firms with a moderate risk threshold than to firms with a high risk threshold. This comparison indicates that  $tv$ -type synergy would be more risky than  $ov$ -type synergy because  $tv$ -type synergy depends on returns of both IT investment units. Similarly, to generalize the results, we solve the problem analytically and make the following propositions.

*Proposition 2A. When  $\delta < \frac{r_2 - r_1}{r_1 + r_2}$ , the firm with high risk tolerance benefits from*

*the enhancement of one-way super-additive value IT synergy if  $\frac{r_1 / \sigma_1}{r_2 / \sigma_2} > \rho$ .*

*Proposition 2B. When  $\delta < \frac{r_2 - r_1}{r_1 + r_2}$ , the firm with low risk tolerance cannot benefit*

*from the enhancement of one-way super-additive value IT synergy if  $\frac{r_1 / \sigma_1}{r_2 / \sigma_2} < \frac{1}{\rho}$ .*

We can explain the results of the experiments with reference to Figure 2.11. This figure illustrates how decisions regarding IT synergy enhancement can affect the portfolio return/risk relationship. This shows that IT synergy enhancement results in a shift in the portfolio. The arrows indicate possible shifts in an IT portfolio following IT synergy enhancement. The shift in Figure 2.11 illustrates an instance of the consequence of IT synergy enhancement. This implies that when the marginal increase in return over risk is smaller than the tangent of the efficient frontier at a low risk but is greater than that at a high risk, the positive return/risk relationship results in a new efficient frontier that is predicted in our experiments.

#### **6.4 Measurement of IT Synergies**

Our IT portfolio selection framework proposes the measurement of  $\alpha$ ,  $\beta$ , and  $\delta$ . In this section, we'd like to discuss possible measures of those synergy coefficients. The measure of  $\alpha$  refers to the degree of IT share between two units. Because enhancement of  $c$ -type synergy becomes feasible when the resources of the two units are related, the IT relatedness measures developed in Tanriverdi (2006) can be a proxy of the degree of IT resource sharing. The IT relatedness measure includes relatedness of IT strategy-making processes, IT relationship management processes, IT infrastructure and IT human resource management processes. Another possible way of measuring  $\alpha$  is to count the number of

individual IT infrastructure items directly. The individual IT infrastructure items may include the number of PCs, number of local area networks, number of LAN nodes, number of mainframes, number of workstations, and number of terminals.

The measure of  $\beta$  should reflect the degree of the effect of IT infrastructure on an IT application. There are two possible ways to measure it. First, the benefit of greater IT infrastructure can be estimated by technical specifications. The performance of software relies on the technological capacity of hardware, such as CPU and memory, and the performance of web applications is determined by the network speed. For example, if the network speed increases from 1 bps to 10 bps, the amount of data that can be transmitted through the web application becomes ten times at maximum. Second, IT experts can empirically test the effect of IT infrastructure. Theoretical calculations often yield unrealistic estimation. Thus, if the performance of an information application can be tested with different capacities of IT infrastructure, the effect can be measured.

The two-way super-additive value IT synergy is enhanced as information and knowledge used by the two units are increasingly related. Thus, the measure of business relatedness of the two units can be a proxy of  $\delta$ . As the business of the two units are more related, each unit can benefit more from exchanging information and data from the other unit. For instance, in a multi-business firm,  $\delta$  of two business units can be measured by degree of overlaps in customers and suppliers between the two.

## **7. Conclusions**

This study contributes to the IS field on several points. First, this paper addresses three types of IT synergy and discusses their different effects on the IT portfolio selection.

Although IT resources have been considered a major source of synergy because of their unique characteristics, few studies have articulated the effects of IT synergy on IT portfolio selection, particularly on IT portfolio risk. Our results can be used as an explanation for the survey of Forrester Research (2004). According to their study, the sector of EAI declined since 2001. The decline was different from their expectation because integration has been considered a solution that can maximize business values of enterprise systems. Our explanation is that firms of low risk threshold may not want to invest in the integration because the IT synergy enhancement would cause a suboptimal IT portfolio with a higher portfolio risk though it has a positive expected return.

Second, this study provides a methodological framework that helps firms to find a practical solution for their IT portfolio selection problems. A firm can use the efficient frontier as a tool in selecting an optimal IT portfolio after evaluating its risk threshold. This tool can also be used to find a firm's range of portfolio selection and possible outcomes for different IT portfolios, and to predict the marginal portfolio return it can earn by taking a unit of portfolio risk. This study extends the financial portfolio selection models by presenting IT investment problems from the perspective of the CIO. The model can provide a practical solution when we consider the fact that the main concern of most firms is their financial performance. Our model captures not only the essence of the problem of the general investor, namely, that of balancing return and risk, but also the characteristics of IT problems, that of IT synergy enhancement. Thus, the model can be distinguished from portfolio selection models in other areas.

Last, our analysis can help firms make decisions regarding the ways to integrate their information systems. Firms may focus on a certain type of IT synergy to achieve their goals of maximizing return and minimizing risk. In the real world, IT synergy is not free to gain. Additional costs of integration will occur to enhance *tv*-type synergy, and additional coordination costs will occur to increase *c*-type synergy. Thus, it is important to predict and estimate the benefits of each type of IT synergy. According to our computational and analytical studies, firms with a low risk threshold are less likely to benefit from IT synergy; thus, we can suggest that these firms should not spend large sums of money to enhance *ov*- and *tv*-type synergy. Based on the results, we would like to suggest that firms with a moderate risk threshold focus on *c*- and *ov*-type synergy and firms with a high risk threshold focus on enhancing *tv*- or *ov*-type synergy.

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## Tables and Figures

**Table 2.1 Three Types of IT Synergy**

Type	Sub-additive cost IT synergy ( <i>c</i> -type synergy)	One-way super-additive value IT synergy ( <i>ov</i> -type synergy)	Two-way super-additive value IT synergy ( <i>tv</i> -type synergy)
Definition	Additional value created when there is sharing of common IT resources between two IT units	Additional value created by the relationship between two IT units (A and B), in which the value of one IT unit (A) is significantly influenced by the value of the other IT unit (B), but the value of B is rarely influenced by the value of A	Additional value created by the relationship between two IT units, in which the return rate of one IT unit is affected by the value of the other IT unit
Key characteristics of the IT resource related to synergy	Capability of remote and simultaneous use	Heavy dependence of IT applications on the IT infrastructure; applicability across a wide range of businesses and industries	Integration; applicability across a wide range of businesses and industries
Theoretical orientation	Economies of scope (Panzar and Willing 1981, Teece 1980, 1982, Willing 1978); relatedness of resources (Farjoun 1998, Robins and Wiersema 1995, Tanriverdi 2006)	Asymmetric complementarities; complementarities of IT infrastructure (Zhu 2004)	Complementarities between IT resources (Milgrom and Roberts 1990, 1995, Tanriverdi and Venkatraman 2005)
Examples	IT machines, IT human resources, and other IT resources can be shared across different business units or functional groups.	The performance of enterprise applications depends on the hardware and networks on which the programs are running. But, the performance of the IT infrastructure is not influenced by the applications	Marketing information systems, new product development systems, and customer service systems can create additional information and value by exchanging data and business processes.

**Table 2.2 Portfolio Data Used for IT Portfolio Selection**

Attributes of IT investment units	IT investment for business unit 1 ( $i = 1$ )	IT investment for business unit 2 ( $i = 2$ )	IT investment for IT infrastructure ( $i = 3$ )
ROI	1.3	4.0	2.2
Standard deviation	1.1	2.5	1.3
Lower bound of $x$ (proportion)	0.1	0.1	0
Upper bound of $x$ (proportion)	0.75	0.75	0.4
$c$ -Type synergy	$\alpha_{13} = 0; \alpha_{12} = 0.3$	$\alpha_{23} = 0; \alpha_{21} = 0.3$	$\alpha_{13} = \alpha_{12} = 0$
$ov$ -Type synergy	$\beta_{13} = 0; \beta_{12} = 0$	$\beta_{23} = 0; \beta_{21} = 0$	$\beta_{31} = 0.5; \beta_{32} = 0.5$
$tv$ -Type synergy	$\delta_{12} = 0; \delta_{31} = 0$	$\delta_{12} = 0; \delta_{31} = 0$	$\delta_{12} = 0; \delta_{31} = 0$
Correlation	$\rho_{12} = 0.3; \rho_{13} = 0.1$	$\rho_{21} = 0.3; \rho_{23} = 0.1$	$\rho_{31} = 0.1; \rho_{32} = 0.1$

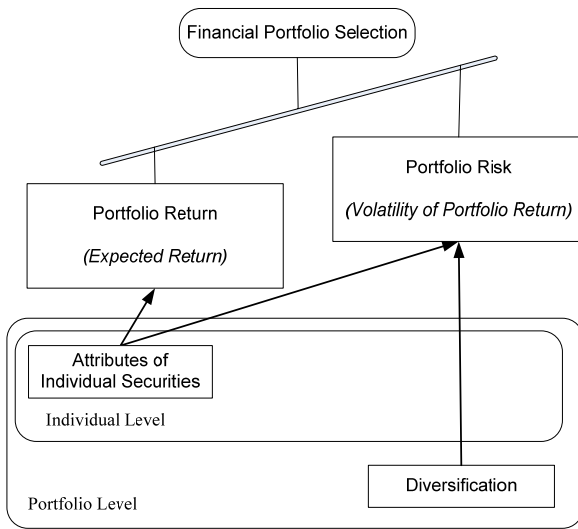
**Table 2.3 Solutions for Optimization of the IT Portfolio**

Risk threshold (risk appetite)	$x_1$ (for business unit 1)	$x_2$ (for business unit 2)	$x_3$ (for IT infrastructure)
1.11	0.737	0.200	0.063
1.14	0.674	0.219	0.107
1.19	0.617	0.264	0.118
1.24	0.558	0.311	0.131
1.32	0.496	0.359	0.145
1.40	0.430	0.411	0.160
1.50	0.360	0.466	0.174
1.61	0.286	0.527	0.187
1.74	0.207	0.598	0.195
1.97	0.200	0.750	0.050

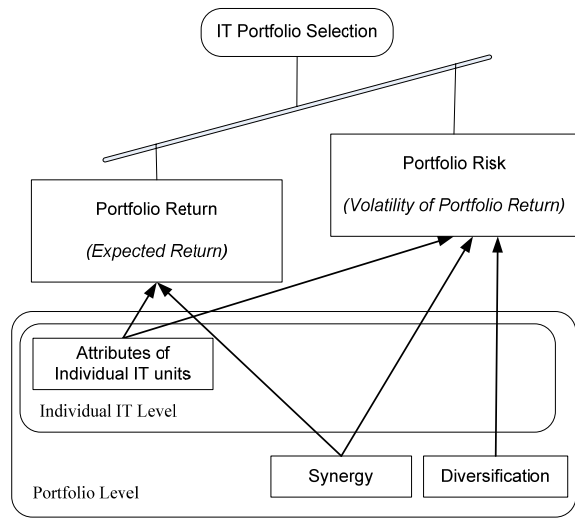
**Table 2.4 IT Investment Data for the Computational Studies**

ROI of IT investment units	I (25%)	II (25%)	III (25%)	IV (25%)
Unit 1	1	1.9	2.1	3
Unit 2	2.5	2	5	4.5

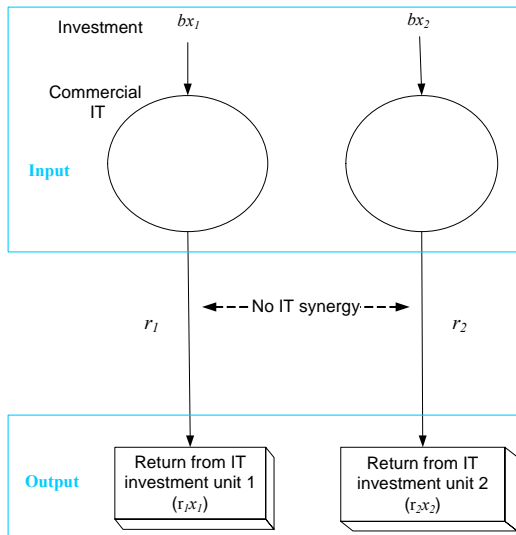




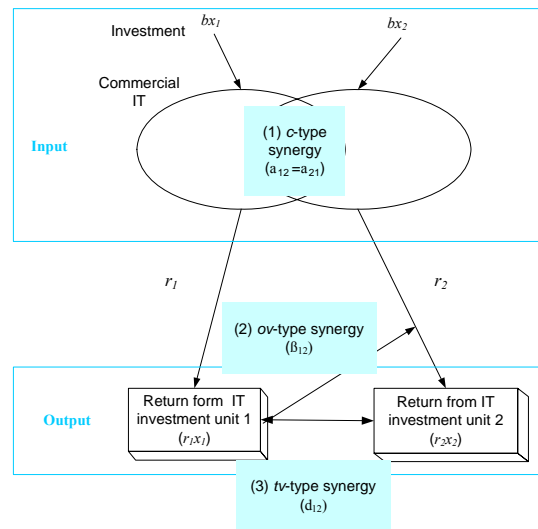
**Figure 2.1 Framework for Markowitz's Portfolio Selection**



**Figure 2.2 Framework for IT Portfolio Selection**



**Figure 2.3 Evaluation of Two IT Investment Units When IT Synergy Is Not Considered**



**Figure 2.4. Evaluation of Two IT Investment Units as a Portfolio When IT Synergy Is Considered**

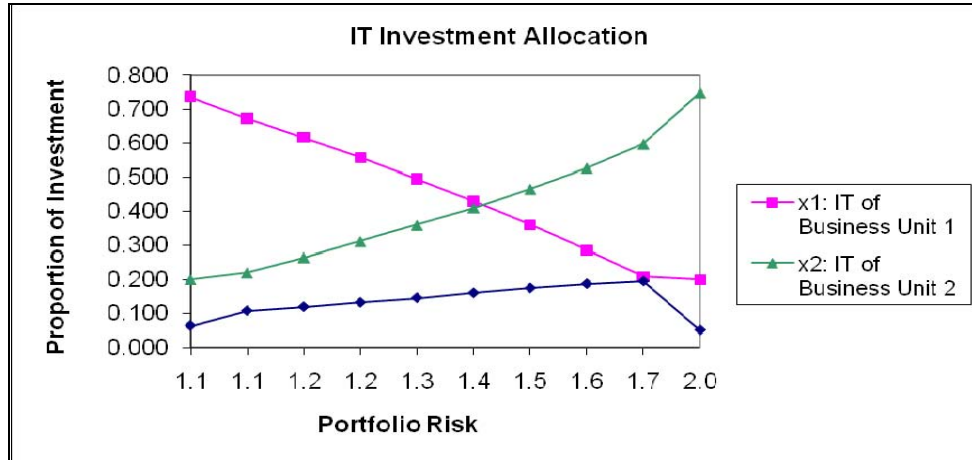


Figure 2.5 Solutions for the IT Portfolio Optimization Problem (with Data Shown in Table 2)

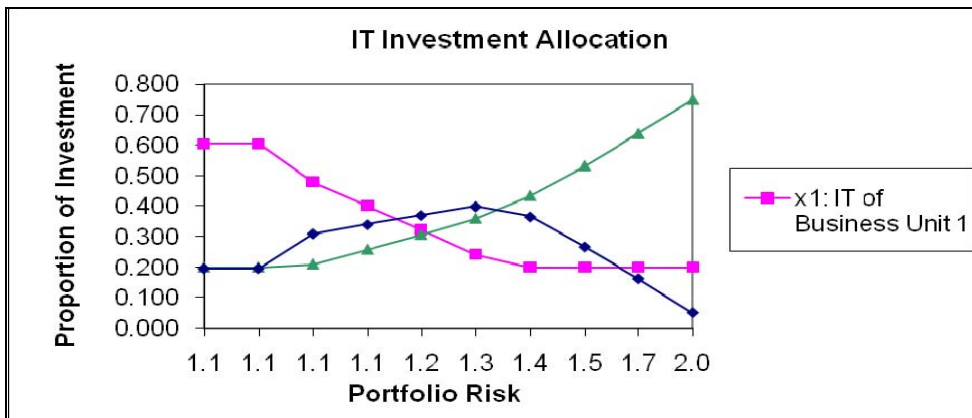


Figure 2.6 Solutions for the IT Portfolio Optimization Problem (with Smaller Degrees of  $c$ - and  $ov$ -Type Synergy)

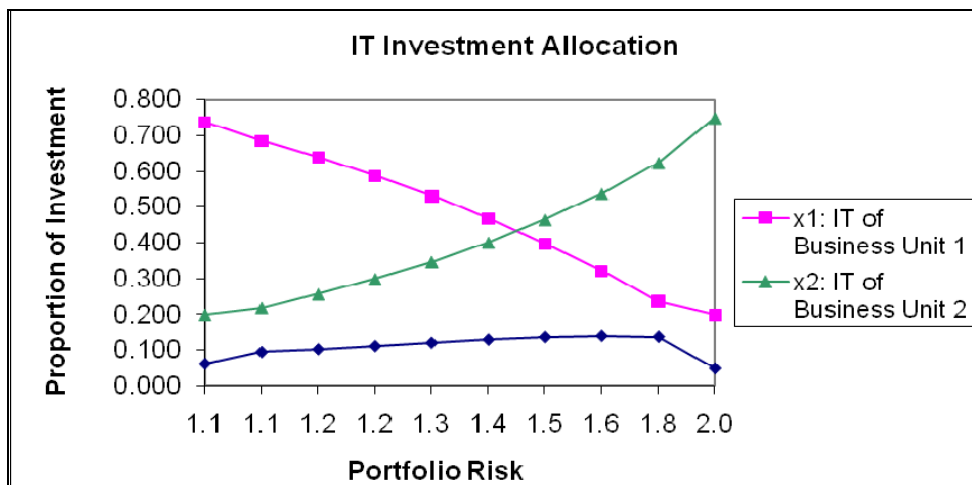
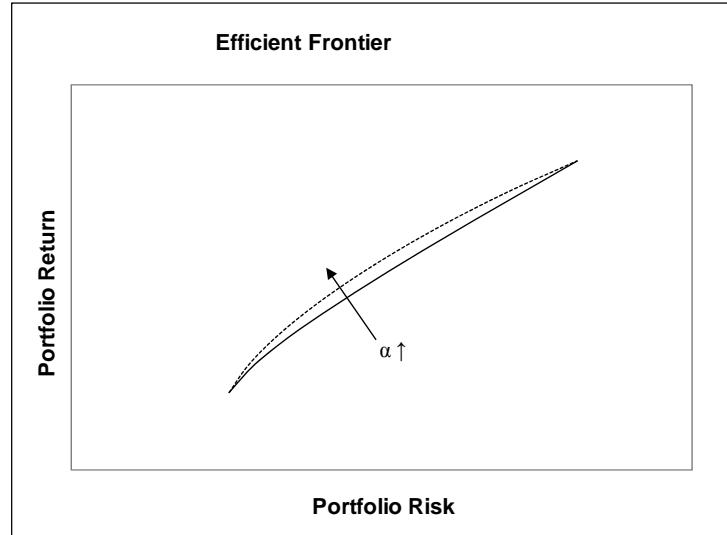
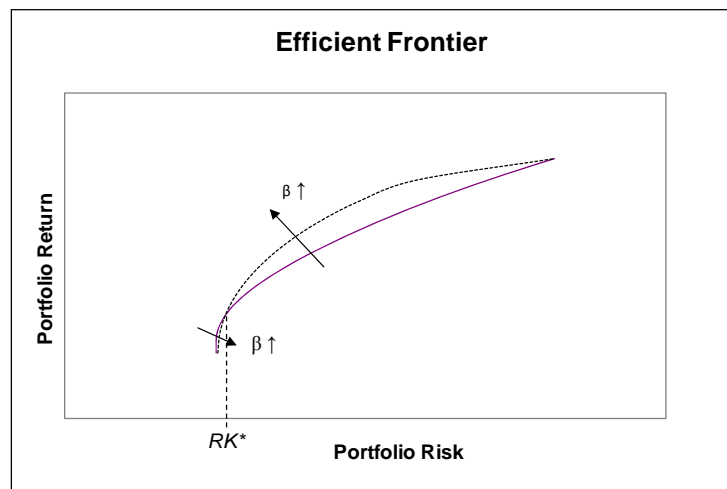


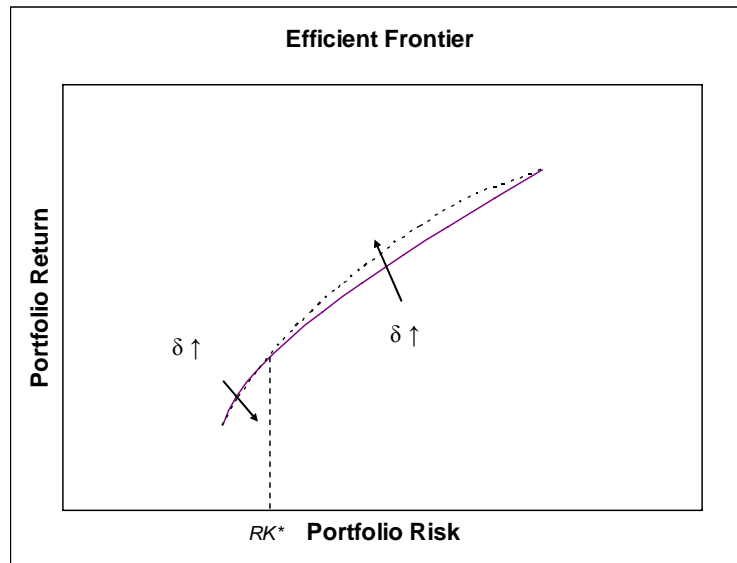
Figure 2.7 Solutions for the IT Portfolio Optimization Problem (with  $tv$ -Type Synergy Instead of  $c$ -Type Synergy)



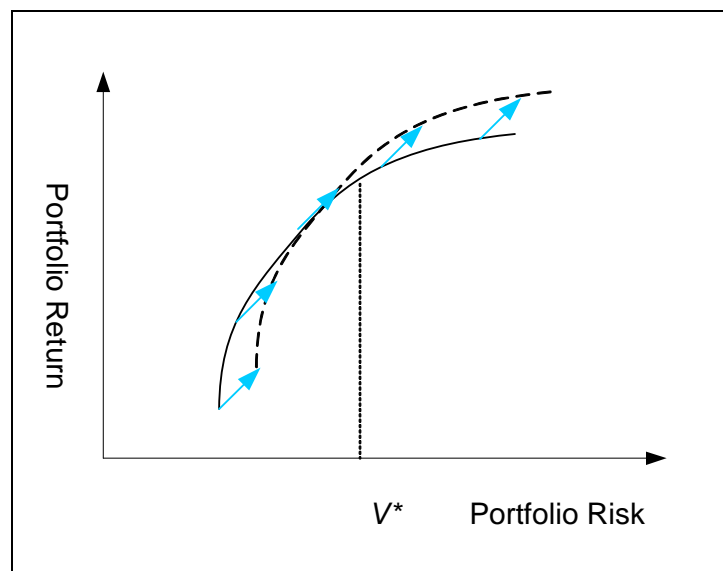
**Figure 2.8 Change in the Efficient Frontier with Different Degrees of Sub-additive Cost Synergy**



**Figure 2.9 Change in the Efficient Frontier with Different Degrees of One-Way Super-additive Value Synergy (When the Low-Return and Low-Risk IT Unit Has a One-Way Super-additive Value Relationship with the High-Return and High-Risk IT Unit)**



**Figure 2.10 Change in the Efficient Frontier with Different Degrees of Two-Way Super-additive Value Synergy**



**Figure 2.11 Shift of the Efficient Frontier Resulting from IT Synergy Enhancement**

## **CHAPTER 3. IT PROJECT PORTFOLIO SELECTION: APPLICATION OF DATA ENVELOPMENT ANALYSIS**

### **1. Introduction**

Balancing return and risk is one of the most essential problems in selecting a portfolio. According to Markowitz's portfolio selection theory (Markowitz, 1952), investors select a financial portfolio on the efficient frontier, which is defined as a set of portfolios yielding maximized return, given a specific level of risks, or that minimize risk, given a specific return. In finance, return/risk relationship is positively linear. However, in the IT investment, return/risk relationship may not be linear (Tanriverdi and Ruefli 2004). Though many different models have been proposed for IT project selection, there have been few models that incorporate the issue of non-linear return/risk relationship in IT investment. Motivated by the non-linear return/risk relationship, we develop a project selection model that is based on a Data Envelopment Analysis (DEA) model.

Another issue in considering IT project risk is that there is few standardized metrics for project risk. We were able to affirm that firms are using different metrics to measure project risk from interviews with practitioners. These issues motivate us to apply DEA model because one of advantages of the model is that it requires neither a specific measure unit nor consistent units among variables.

In this study, we use the term "IT portfolio" to indicate a set of IT projects in the firm. We focus on IT project portfolios because most IT components in a firm are generally

to be customized for the organization; thus, the IT components are installed in or adjusted to the organization through IT projects. The management of the IT project portfolio is concerned with investment decision making for IT projects that are ready to implement and it takes up the largest proportion of IT investments (Maizlish and Handler 2005).

Our research is motivated by the question: How do CIOs achieve the optimal IT portfolio, balancing the strategic and operational projects? The purpose of our study was to provide a framework that would help firms conduct a strategic analysis of their enterprise IT investments. In particular, we consider the impact of the portfolio risk on IT portfolio selection from the perspective of the CIO.

## **2. Theoretical Background**

### ***2.1 Portfolio Selection Theories***

Portfolio research has been studied primarily in the area of financial asset management. A portfolio is defined as a collection of investments held by an organization or an individual investor. One of the key ideas in the portfolio selection problem is to balance return and risk. Both the financial portfolio and the IT portfolio have ideas in common in that sense. In general, an investment with higher expected return comes with higher expected risk, and an investment with smaller expected return comes with a lower level of risk. Investors desire not only to maximize the expected return of the portfolio, but also to minimize the expected risk of the portfolio. Thus, portfolio optimization refers to finding a portfolio that maximizes the expected return at a given level of risk, or that minimizes the expected return at a given level of return. The optimization problem can be

presented in diverse forms depending on the formulation of the objective function and constraints. Both financial and IT portfolios will have various constraints, including an investment budget, investment priorities, and compliance issues.

There are several differences between the two portfolio types. First, unlike selection of the financial portfolio, the estimation of the expected return of the IT portfolio can be very subjective, because it consists of multiple-dimensional values, including a reduction in costs, an increase in productivity, growth, synergy enhancement, and so on. The return of securities is estimated by historical data, but the return of an IT project is determined by experts' subjective evaluation. Second, the financial investments can be retractable by selling the financial products, but IT investments are hardly ever retractable. It takes considerable time to implement and complete an IT portfolio. It often takes 6 months through a few years to complete an IT project. Last, the number of decision variables in typical security portfolio optimization problems is typically small. However, large companies, including the four companies that have cooperated in our research, have hundreds of proposed projects.

We aim to develop a model for selection of a firm's IT portfolio. Since various IT project selection models have been proposed, our study is an extension of prior IT portfolio research. However, there have been limited prior studies that have investigated the consequences of firm investments in project selection from a portfolio perspective, in which the main concern is to balance the return and risk of IT investments.

## ***2.2 IT Project Selection and the IT Portfolio***

Our study focuses on the managerial problem of selecting IT projects. IT project selection has emerged as a research topic because the size and scope of IT investments in firms have become increasingly significant. IT use in firms has become more diversified, and IT now plays more critical roles in business functions. It is difficult to find a business process that is not associated with IT, either directly or indirectly. Thus, IT has become intertwined throughout the firm and the concept of the IT portfolio has emerged. In the early 1980s, McFarlan (1981) used the concept of the IT portfolio in proposing a quantitative method to manage IT risk. However, it is only quite recently that this concept has again been increasingly discussed in IT research. Berinato (2001) suggested that IT managers view the company's IT projects as a portfolio and use mathematics in their decision making, similar to the way a portfolio analysis is used in the area of finance. Maizlish and Handler (2005) and Kaplan (2005) have reinterpreted the IT issues of a firm from the point of view of a portfolio and have provided a comprehensive description of the IT portfolio.

Several methodologies for selecting IT projects have been proposed. Lucas and Moore (1976) discussed an IT project selection methodology based on a scoring model. Bacon (1992) and Santhanana and Kyparisis (1995) discussed multiple criteria in the problem of information systems (IS) project selection. Lee and Kim (2000) developed an IT project selection methodology using an analytic network process, within a zero-one goal programming model. Dickison et al. (2001) and Santhanana and Kyparisis (1996) emphasized the interdependency of technology projects and proposed a model for IT



portfolio optimization using a dependency matrix. Verhoef (2002) proposed quantitative methods to manage the IT portfolio and described various IT problems in mathematical ways. Lin and Hsieh (2004) used fuzzy theory in their model of IT portfolio selection.

In terms of selection criteria, various categorizations can be applied. Lucas and Moore (1976) presented potential criteria for scoring models in IS projects, including tangible and intangible benefits, the timing of costs and benefits, and the impact on existing operations. Bacon (1992) proposed four categories of criteria for IT investments: cash flow-related financial criteria, non-cash flow-related financial criteria, management criteria, and development criteria. From interviews with more than 10 senior IT managers in four US Fortune 500 firms, we found that companies have their own criteria and measurements for each criterion, which requires a selection method that does not use specific variables and measurements. Thus, DEA can be an appropriate candidate of the selection method.

### ***2.3 Data Envelopment Analysis (DEA)***

Data Envelopment Analysis (DEA) can be used to prioritize the decision making units (DMUs), and DEA has been applied in various areas including regulatory factors (Delmas and Tokat 2005), innovation implementation (Linton and Cook 1998), and Internet company evaluation (Serrano-Cinca et al. 2003). DEA evaluates the efficiency of DMUs using input and output data of individual DMUs. DMUs on the efficient frontier (production frontier) are considered efficient DMUs, and other units that are not laid on the efficient frontier considered inefficient units. The efficiency score of the efficient units is

equal to one and that of inefficient units is calculated by the distance of the DMU from the efficient frontier.

DEA has several advantages over other methods in examining decisions among alternatives that have high uncertainty (Linton et al. 2002). First, DEA is a data driven method; thus, it is proven to be useful to uncover hidden relationship. Users do not need to have explicit mathematical forms between inputs and outputs. Second, DEA is capable of handling multiple inputs and outputs. Third, DEA can be used with heterogeneous metrics of inputs and outputs.

### **3. Model Development**

Our model is based on the framework developed in Markowitz's portfolio selection theory. We view the portfolio selection as the problem of balancing the return and risk of IT investments (Markowitz 1952). Like the definition of risk in a financial portfolio analysis, risk of the value of IT is defined as the volatility of the expected IT return. With the assumption of risk-averse investors, investors seek a portfolio that minimizes portfolio risk at a given level of portfolio return.

As a tool of balancing return and risk, we apply DEA methods. DEA is a non-parameter method that calculates the efficiency of DMUs based on input/output data of individual DMUs and then ranks them. In this study, because inputs are what organizations are to minimize and outputs are what they are to maximize, we regard project risk as an input and project return as an output in applying the DEA method. The DMUs were the individual proposed IT projects; thus, DEA is used to identify the efficiency of proposed IT projects and rank them. IT portfolios could then be selected by projects' rankings.

Since organizations desire to maximize investment return and to minimize investment risk, a simple criterion of project selection can be the ratio between return and risk. However, the return/risk ratio of individual proposed project might not be appropriate because the return/risk relationship of efficient IT investments is nonlinear (Tanriverdi and Ruefli 204). The maximum return of an investment would rely on the level of risk of the investment. Thus, we proposed an IT project selection method based on the efficiency of the single input-single output DEA model because the model does not assume constant relationship between return and risk of efficient projects.

### ***3.1 Project Efficient Frontier***

The basic idea in our IT portfolio selection (ITPS) model is to rank projects according to their efficiency based on DEA model and to select projects based on this ranking. The efficiency of individual IT projects is derived from the distance between the position of an IT project and the efficient frontier at a given risk. The efficient frontier of an IT portfolio can be defined as links of the projects whose efficiency is equal to one. The efficient projects have the highest expected return at a given level of expected risk or should have the minimum expected cost at a given level of expected return. Figure 3.1 illustrates the efficient frontier in the DEA Banker-Charnes-Cooper (BCC) model. The efficiency of an IT project, the efficiency of which is not equal to one, is defined as the ratio between the maximum expected return, given the specific risk of the project, and the actual expected return of the IT project.

### 3.2 ITPS (IT Portfolio Selection) Model

We propose IT portfolio selection (ITPS) by applying a DEA model. DEA is a mathematical tool that ranks decision-making units by their efficiency, and the efficiency of a decision-making unit is determined by the maximized ratio between the virtual input and the virtual output (Cooper et al. 2006). The ITPS model is used to measure the efficiency of each proposed project, given the data on expected return and the expected risk of individual projects. Suppose we have  $n$  proposed projects to evaluate; let an project  $j$  be evaluated, where  $j$  ranges over  $1, \dots, n$ . Applying the one-input one-output DEA model, the efficiency of project  $j$ ,  $\theta_j$ , can be obtained as shown below:

$$Max_{u,v} \theta_j = \frac{uy_j - u_0}{vx_j} \quad (j = 1, \dots, n) \quad (3.1)$$

$$\begin{aligned} \text{subject to} \quad & \frac{uy_j - u_0}{vx_j} \leq 1 \\ & , \\ & 0 \leq u \leq 1 \\ & 0 \leq v \leq 1 \end{aligned}$$

$x_j$  and  $y_j$  are estimated risk and return of project  $j$  respectively.  $u$  and  $v$  is weight on the return and on risk, respectively, that maximize the efficiency in the DEA. The variable  $u_0$  is a free variable that is defined in the DEA, particularly in BCC models (Cooper 2005). If  $u_0$  is zero, the model above will be an application of the Charnes-Cooper-Rhodes (CCR) model, which can be regarded as a simplified BCC model.

## 4. Analysis of ITPS Models using Computational Studies

In this section, we conducted experiments to verify the expected benefits of the ITPS model by illustrating the different outcomes of the two project selection methods. We

compare our ITPS model an alternative selection model that is based on the return/risk ratio using Monte Carlo methods, and discuss consequences of the model choice.

We consider two types of IT projects in this experiment: low return/risk ratio projects (type I projects) and high return/risk ratio projects (type II projects). The type I project refers to operational projects of which expected return can be accomplished in a short-term (e.g., projects for better operational margins), and the type II project refers to strategic projects of which expected return can be obtained in a long-term (e.g., projects for firm's long term growth). In general, the risk of an investment increases as its expected return increases. However, the return/risk relationship of efficient IT investment is not linear (Tanriverdi and Ruefli 2004). Instead, the efficient frontier is often concave as shown in Figure 3.1 because the marginal risk of the efficient project is likely to increase as the expected return increases.

We consider an alternative model that firms can use to select IT projects. Since firms desire to maximize return at a given level of risk and to minimize risk at a given level of return in general, the ratio between estimated return and risk of an IT project can be used in evaluating individual projects. However, when the return/risk ratio is used as the criteria of project selection, less number of strategic projects can be selected because the efficient frontier is often concave. This outcome can be inefficient since strategic projects are beneficial for long term financial profits of the firm (Weill 1990). Thus, we intend to test whether the model based on DEA efficiency selects greater number of strategic projects than the alternative model based on the return/risk ratio.

We designed an experiment of project selection using a Monte Carlo method. The proposed projects consist of 25 type I projects and 25 type II projects. The risk of type I projects are generated by  $2 + 2 \cdot rand()$ , where  $rand()$  is a random number between zero and one, and that of type II projects are generated by  $3 + 3 \cdot rand()$ . The return of type I projects are generated by  $(2 + 2 \cdot rand()) \cdot risk$  and that of type II projects by  $(1.5 + rand()) \cdot risk$ . We generate 50 sets of the project data to test our hypothesis statistically. We hypothesized that the model based on DEA efficiency is likely to select greater number of strategic projects than the alternative model based on the return/risk ratio.

To focus on the return/risk relationship, we assume the expected costs of the projects are even. We consider a firm that can afford to implement only half of the proposed projects due to limited IT budget and resources, so it needs to select 25 projects out of 50 projects. Table 3.1 shows the results of project selection by the ITPS model and the alternative model. In the setting of the computational study, our hypothesis was supported according to t-test as shown in Table 3.1. When 25 operational projects and 25 strategic projects are proposed, on average 4.6 strategic projects are selected when the alternative model is used. However, when the ITPS model is used, on average 7.8 strategic projects are selected. The ITPS model based on DEA is likely to select greater number of strategic projects than the model based on the return/risk ratio because P-value of t-test with 50 samples is 0.00.

The results imply that ITPS model is a more appropriate quantitative model than the alternative selection model which is based on return/risk ratio of individual projects when a firm intends to more focus on strategic projects. Though most firms desire to maximize

portfolio return and to minimize portfolio risk, using the return/risk ratio as the criterion of project selection can be inefficient because it might result in the selecting too small number of strategic projects. The importance of strategic projects has been addressed in prior literature (e.g., Weill 1990). Considering the fact that the marginal risk of an investment increases as the return of the investment increases, we proposed the ITPS model, which can be useful since it can provide firms with more balanced IT portfolio.

## **5. An Extension of the ITPS Model**

An advantage of DEA models is that inputs and outputs may not be measured by a specific quantitative metric. Each input or output can be measured with its own metrics. For example, in evaluating branches of a retailer with inputs of the number of employees and the operation cost, the unit of measurements for the two inputs may be different. This advantage of DEA can be useful in project selection, particularly when a firm selects projects based on three dimensions of project data: expected cost, risk, and benefit. Costs and benefits are measured in monetary metrics (e.g., US dollars) in many firms. However, the project risk can be measured by various ways, including success probability, failure probability, variance of return, and so on (Tanriverdi and Ruefli 2004). According to our interviews with practitioners, including senior IT managers in four Fortune 100 firms, a company uses a 10 scale score metric to measure project risk, another company uses a categorical metric (low, medium, high), and other firms uses the range of cost and benefit to measure project risk.

The expected cost and risk of projects are what a firm desires to minimize; thus, it is reasonable to regard the cost and risk as two inputs of projects. The expected benefit can be

the output of a project. We propose a two-input one-output DEA model for project selection. The efficiency of project  $j$  can be obtained by solving the following optimization model.

$$\underset{u, v_1, v_2}{Max} \theta_j = \frac{uy_j - u_0}{v_1x_{1j} + v_2x_{2j}} \quad (j = 1, \dots, n) \quad (3.2)$$

$$\begin{aligned} \text{subject to} \quad & \frac{uy_j - u_0}{v_1x_{1j} + v_2x_{2j}} \leq 1 \\ & 0 \leq u \leq 1 \\ & 0 \leq v \leq 1 \end{aligned}$$

$x_{1j}$ ,  $x_{2j}$  and  $y_j$  are estimated cost, risk and return of project  $j$  respectively. This model can help firms evaluate the efficiency of individual projects with heterogeneous metrics of risk measures and cost measures.

We conducted an experiment to examine how the two inputs are balanced in the project selection and whether the unit of measurement does not affect the outcome. In this experiment, we consider a set of proposed projects that consists of eight types of projects depending on its estimated cost, risk, and return. We assume that a set of 80 proposed projects consists of the eight types of projects, and the number of projects for each type is ten. Similar to the earlier experiment, we assume a firm should select half out of the proposed projects. Thus, the firm should select 40 out of 80 projects should be selected based on DEA efficiency. Table 3.2 describes eight types of projects and the results of the project selection for each type. We run the project selection model five times using different scale measures, but we obtained identical results. It ascertains that the extended ITPS model is an effective method for the problem of heterogeneous metrics of variables.



According to the results shown in Table 3.2, the projects of which estimated benefit are high are most likely to be selected, which is consistent with our expectation. It seems the project profile {cost, risk} does not influence much in the experiment. The number of projects with low cost is 21 and the number of projects with low risk is 19, which means the weight of the two factors appears to be balanced well. That is to say, the two factors are likely to be equally weighted in the project selection regardless heterogeneous measures of the variables. It is because the efficiency of a project is calculated with the maximum return at a given level of cost and risk and the efficiency determines whether the project is selected or not.

## **6. Conclusions**

As the role of IT has become increasingly critical to a firm's performance, the size of IT investments in large firms has increased up to billions of dollars per year. IT investment often requires a big financial commitment; thus, decisions on IT portfolio selection can be critical for the performance of the investment. IT investments of \$1 billion may be worth \$2 billion by creating new business values in the long term, or they can just be an obstacle to the firm's need to innovate, depending on the decisions in IT portfolio selection.

One of the contributions of this study is that we propose a project selection model that does not assume the linear return/risk relationship of IT investments. There will be no silver bullet method for IT portfolio selection by a firm, because each firm has different IT resources, business settings, IT needs, and environments. However, our model can solve an

apparent issue of the return/risk relationship of IT investment by applying DEA models and uses the DEA efficiency as a criterion of project selection.

Another methodological contribution is that our model can be a practical solution for the firms that do not use standardized risk measures. According to our survey, firms are using different metrics to evaluate project risks. Unlike the risk of financial products, there have been no standardized metrics for IT risk or IT project risk, thus DEA that can be used with heterogeneous measures among variables is an appropriate approach to evaluate individual IT projects.

In addition, this study uses a computational method to hypothetically examine the validity of our proposed model. Since Fox and Baker (1985) used a simulation program to support their research arguments, few studies have made use of computational methods for project selection research. We believe our study demonstrates an example of the use of the computational method and is able to motivate other studies that use simulation methods in the research streams of project selection and IT investment. In addition, our computational methodology can be applied other decision making problems of which core issues are balancing return and risk.

There are several limitations to our study. First, DEA methods are limitation themselves. The method does not incorporate decision makers' preference. Regardless risk averseness of organizations, this method will yield same results. It can be a good extension to develop a model that considers decision makers' preferences. Second, our computation method is limited in terms of coverage of possible variable values. Due to open range of variables, we conduct experiments only with reasonable settings. Third, we assume that

individual firms have valid and consistent measurements of the project return and the risk, but we did not discuss the issue of measuring the return and risk. Future research might focus on developing measurement methods to establish standard in IT risk measurement.

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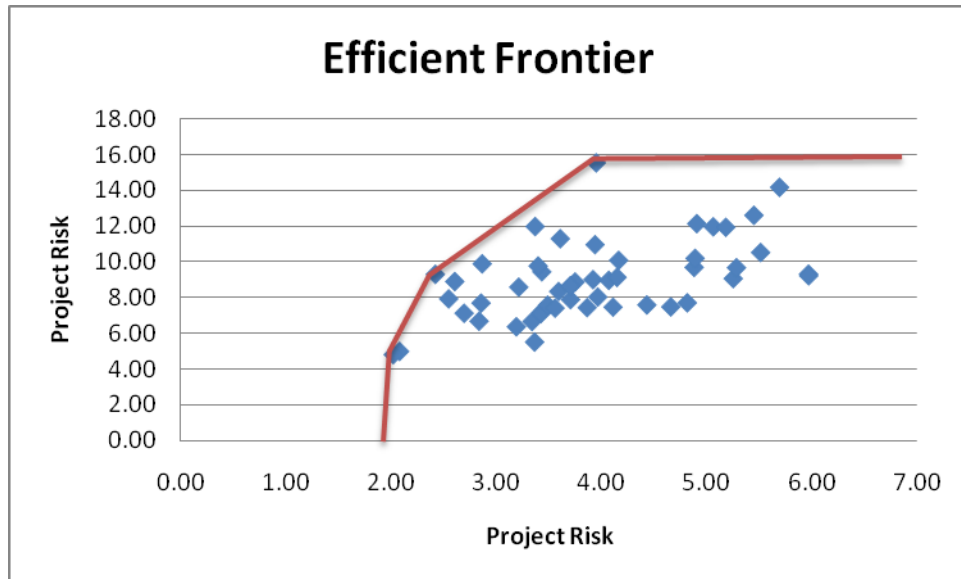
## Tables and Figures

**Table 3.1 Comparison between the ITPS model and the alternative model**

	The alternative model based on the return/risk ratio	ITPS model based on DEA
The number of Type II project (mean)	4.16	7.80
Percentage of Type II project in the IT portfolio (mean)	9.40%	15.60%
Pr( $T < t$ ): t-test	0.00	

**Table 3.2 Project types and selection with the extended model**

Project Type	Cost	Risk	Benefit	Selection
1	Low	Low	Low	3/10
2	Low	Low	High	7/10
3	Low	High	Low	1/10
4	Low	High	High	8/10
5	High	Low	Low	1/10
6	High	Low	High	10/10
7	High	High	Low	2/10
8	High	High	High	8/10



**Figure 3.1 Efficient frontier**

## Appendix A. Sample Project Data for IT Portfolio Selection

$$\Delta_v = \begin{bmatrix} 11.1 & 5 & 2.1 & 0 & 0 & 3.1 & 0 & 0 & 4.2 \\ 0 & 11.8 & 2 & 0 & 3 & 0 & 2.2 & 1.9 & 0 \\ 0 & 0 & 14.2 & 3.4 & 2 & 2.1 & 0 & 0 & 3 \\ 0 & 0 & 0 & 11.5 & 0 & 0 & 1.9 & 0 & 0 \\ 0 & 0 & 0 & 0 & 6.1 & 3 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 4.1 & 2 & 2.4 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2.4 & .9 & 2.1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8.2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 7.2 \end{bmatrix},$$

$$\Delta_c = \begin{bmatrix} 5.1 & -5 & 0 & -1.1 & -7 & -4 & 0 & 0 & -3 \\ 0 & 3.9 & 0 & -3 & 0 & 0 & 0 & -2 & 0 \\ 0 & 0 & 5.3 & -1.2 & 0 & 0 & -3 & 0 & 0 \\ 0 & 0 & 0 & 4.2 & 0 & -3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2.4 & -3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2.6 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4.2 & -2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3.1 \end{bmatrix},$$

$$\Sigma_v = \begin{bmatrix} 9 & 3 & 0 & -3.6 & 1.2 & 0 & 0 & -7 & .5 \\ 3 & 25 & -2 & 0 & 0 & -1.6 & - & .2 & 0 \\ 0 & -2 & 18 & 0 & -3.6 & 0 & 0 & 0 & 0 \\ -3.6 & 0 & 0 & 27 & 0 & 0 & 0 & 0 & 0 \\ 1.2 & 0 & -3.6 & 0 & 13.25 & 0 & 0 & 0 & 1.1 \\ 0 & -1.6 & 0 & 0 & 0 & 2.25 & 0 & .4 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & .49 & 0 & 0 \\ -7 & .2 & 0 & 0 & -2.1 & .4 & 0 & 4 & 0 \\ .5 & 0 & 0 & 1.1 & -1.4 & 0 & 0 & 0 & 2.44 \end{bmatrix}$$

$$\Sigma_c = \begin{bmatrix} .25 & .01 & 0 & .2 & .3 & 0 & -.2 & 0 & 0 \\ .01 & 1 & -.16 & .4 & 0 & 0 & -.01 & 0 & .12 \\ 0 & -.16 & .25 & 0 & 0 & 0 & 0 & 0 & 0 \\ .2 & .4 & 0 & 2.25 & 0 & 0 & 0 & .1 & 0 \\ .3 & 0 & 0 & 0 & .25 & 0 & -.14 & 0 & -.13 \\ 0 & 0 & 0 & 0 & 0 & .01 & 0 & -.1 & 0 \\ -.2 & -.01 & 0 & 0 & 0 & 0 & .01 & 0 & 0 \\ 0 & 0 & 0 & .1 & 0 & -.1 & 0 & .16 & 0 \\ 0 & .12 & 0 & 0 & -.13 & 0 & 0 & 0 & .09 \end{bmatrix}$$

## Appendix B. Proofs for Propositions

*Proof for Proposition 1A.* The expected return from a portfolio  $(1-x, x)$  is given by

$$RT(1-x, x) = r_1(1-x) + r_2x + \beta_{12}r_1x(1-x)$$

One way of obtaining the efficient frontier is to require  $RT(1-x, x) = R_0$  where  $R_0$  is a particular expected return desired and then obtain the variance. For a two-fund problem,  $RT(1-x, x) = R_0$  is sufficient to determine the portfolio  $(1-x^*, x^*)$ .

From  $RT(1-x, x) = R_0$ , we have

$$x = \frac{1}{2\beta r_1} [r_2 - r_1 + \beta_{12}r_1 \pm \sqrt{(r_2 - r_1 + \beta_{12}r_1)^2 - 4(R_0 - r_1)\beta_{12}r_1}].$$

We assume that  $\beta$  is a small number; in this case,  $x$  only has one solution within the interval  $[0, 1]$ :

$$x^* = \frac{1}{2\beta r_1} [r_2 - r_1 + \beta_{12}r_1 - \sqrt{(r_2 - r_1 + \beta_{12}r_1)^2 - 4(R_0 - r_1)\beta_{12}r_1}].$$

Consider  $R_0 = r_2 - \varepsilon$  r an arbitrarily small positive number  $\varepsilon > 0$ . Then

$$x^* = 1 - \frac{\varepsilon}{r_2 - r_1(1 + \beta_{12})} + O(\varepsilon^2).$$

Then the variance  $v$  is

$$\begin{aligned} v &= x^{*2} \sigma_2^2 + 2x^*(1-x^*)(1+\beta x^*)\sigma_1\sigma_2\rho + (1-x^*)^2(1+\beta x^*)^2\sigma_1^2 \\ &= \sigma_2^2 + 2\varepsilon \frac{\sigma_1\sigma_2\rho(1+\beta) - \sigma_2^2}{r_2 - r_1(1+\beta)} + O(\varepsilon^2). \end{aligned}$$

Now we obtain the competitive statistics of the variance with respect to  $\beta$ :



$$\frac{\partial v}{\partial \beta} = 2\varepsilon \frac{\sigma_1 \sigma_2 \rho r_2 - \sigma_2^2 r_1}{[r_2 - r_1(\beta + 1)]^2} + O(\varepsilon^2).$$

Thus, when  $\frac{r_1 / \sigma_1}{r_2 / \sigma_2} > \rho$ ,  $\frac{\partial v}{\partial \beta} > 0$ . ■

*Proof for Proposition 1B.* The expected return from a portfolio  $(1-x, x)$  is given by

$$RT(1-x, x) = r_1(1-x) + r_2x + \beta_{12}r_1x(1-x)$$

One way of obtaining the efficient frontier is to require  $RT(1-x, x) = R_0$  where  $R_0$  is a particular expected return desired and then obtain the variance. For a two-fund problem,  $RT(1-x, x) = R_0$  is sufficient to determine the portfolio  $(1-x^*, x^*)$ .

From  $RT(1-x, x) = R_0$ , we have

$$x = \frac{1}{2\beta r_1} [r_2 - r_1 + \beta_{12}r_1 \pm \sqrt{(r_2 - r_1 + \beta_{12}r_1)^2 - 4(R_0 - r_1)\beta_{12}r_1}].$$

We assume that  $\beta$  is a small number; in this case,  $x$  only has one solution within the interval  $[0, 1]$ :

$$x^* = \frac{1}{2\beta r_1} [r_2 - r_1 + \beta_{12}r_1 - \sqrt{(r_2 - r_1 + \beta_{12}r_1)^2 - 4(R_0 - r_1)\beta_{12}r_1}].$$

Consider  $R_0 = r_1 + \varepsilon$  r an arbitrarily small positive number  $\varepsilon > 0$ . Then

$$x^* = \frac{\varepsilon}{r_2 - r_1(\beta_{12} - 1)} + O(\varepsilon^2).$$

Then the variance  $v$  is

$$\begin{aligned} v &= x^{*2} \sigma_2^2 + 2x^*(1-x^*)(1 + \beta_{12}x^*)\sigma_1 \sigma_2 \rho + (1-x^*)^2(1 + \beta_{12}x^*)^2 \sigma_1^2 \\ &= \sigma_1^2 + 2\varepsilon \frac{\sigma_1 \sigma_2 \rho + (\beta_{12} - 1)\sigma_1^2}{r_2 - r_1(1 - \beta_{12})} + O(\varepsilon^2). \end{aligned}$$

Now we obtain the competitive statistics of the variance with respect to  $\beta$ :

$$\frac{\partial v}{\partial \beta} = 2\varepsilon \frac{\sigma_1 \sigma_2 \rho r_2 - \sigma_1^2 r_2}{[r_2 - r_1(1 - \beta_{12})]^2} + O(\varepsilon^2).$$

Thus, when  $\frac{r_1 / \sigma_1}{r_2 / \sigma_2} < \frac{1}{\rho}$ ,  $\frac{\partial v}{\partial \beta} < 0$ .

*Proof for Proposition 2A.* We assume asymmetric super-additive synergy, where

$\delta = \delta_{12} = \delta_{21}$ . The expected return from a portfolio  $(1-x, x)$  is given by

$$RT(1-x, x) = r_1(1-x) + r_2x + \delta r_1x(1-x) + \delta r_2x(1-x)$$

One way of obtaining the efficient frontier is to require  $RT(1-x, x) = R_0$  where  $R_0$  is a particular expected return desired and then obtain the variance. For a two-fund problem,

$RT(1-x, x) = R_0$  is sufficient to determine the portfolio  $(1-x^*, x^*)$ .

From  $RT(1-x, x) = R_0$ , we have

$$x = \frac{1}{2\delta(r_1 + r_2)} [r_2 - r_1 + \delta(r_1 + r_2) \pm \sqrt{(r_2 - r_1 + \delta(r_1 + r_2))^2 - 4\delta(R_0 - r_1)(r_1 + r_2)}].$$

We assume that  $\beta$  is a small number ( $\delta \leq \frac{r_2 - r_1}{r_1 + r_2}$ ); in this case,  $x$  only has one solution

within the interval  $[0, 1]$ :

$$x^* = \frac{1}{2\delta(r_1 + r_2)} [r_2 - r_1 + \delta(r_1 + r_2) - \sqrt{(r_2 - r_1 + \delta(r_1 + r_2))^2 - 4\delta(R_0 - r_1)(r_1 + r_2)}].$$

Consider  $R_0 = r_2 - \varepsilon$  r an arbitrarily small positive number  $\varepsilon > 0$ . Then

$$x^* = 1 - \frac{\varepsilon}{r_2 - r_1 - \delta(r_1 + r_2)} + O(\varepsilon^2).$$

Then the variance  $v$  is

$$\begin{aligned} v &= (1-x^*)^2 (1+\delta x^*)^2 \sigma_1^2 + x^{*2} (1+\delta - \delta x^*)^2 \sigma_2^2 \\ &\quad + 2x^* (1-x^*)(1+\delta x^*)(1+\delta - \delta x^*) \sigma_1 \sigma_2 \rho \\ &= \sigma_2^2 + 2\varepsilon \frac{\sigma_1 \sigma_2 \rho (1+\delta) - \sigma_2^2}{r_2 - r_1 - \delta(r_1 + r_2)} + O(\varepsilon^2). \end{aligned}$$

Now we obtain the competitive statistics of the variance with respect to  $\beta$ :

$$\frac{\partial v}{\partial \delta} = 4\varepsilon \frac{\sigma_1 \sigma_2 \rho r_2 - \sigma_2^2 r_1}{[r_2 - r_1 - \delta(r_1 + r_2)]^2} + O(\varepsilon^2).$$

Thus, when  $\frac{r_1 / \sigma_1}{r_2 / \sigma_2} > \rho$ ,  $\frac{\partial v}{\partial \delta} > 0$ . ■

*Proof for Proposition 2B.* We assume asymmetric super-additive synergy, where

$\delta = \delta_{12} = \delta_{21}$ . The expected return from a portfolio  $(1-x, x)$  is given by

$$RT(1-x, x) = r_1(1-x) + r_2x + \beta r_1x(1-x) + \beta r_2x(1-x)$$

One way of obtaining the efficient frontier is to require  $RT(1-x, x) = R_0$  where  $R_0$  is a particular expected return desired and then obtain the variance. For a two-fund problem,  $RT(1-x, x) = R_0$  is sufficient to determine the portfolio  $(1-x^*, x^*)$ .

From  $RT(1-x, x) = R_0$ , we have

$$x = \frac{1}{2\delta(r_1 + r_2)} [r_2 - r_1 + \delta(r_1 + r_2) \pm \sqrt{(r_2 - r_1 + \delta(r_1 + r_2))^2 - 4\delta(R_0 - r_1)(r_1 + r_2)}].$$

We assume that  $\beta$  is a small number ( $\delta \leq \frac{r_2 - r_1}{r_1 + r_2}$ ); in this case,  $x$  only has one solution

within the interval  $[0, 1]$ :

$$x^* = \frac{1}{2\delta(r_1 + r_2)} [r_2 - r_1 + \delta(r_1 + r_2) - \sqrt{(r_2 - r_1 + \delta(r_1 + r_2))^2 - 4\delta(R_0 - r_1)(r_1 + r_2)}].$$

Consider  $R_0 = r_1 + \varepsilon$  r an arbitrarily small positive number  $\varepsilon > 0$ . Then

$$x^* = \frac{\varepsilon}{r_2 - r_1 - \delta(r_1 + r_2)} + O(\varepsilon^2).$$

Then the variance  $v$  is

$$v = \sigma_1^2 + 2\varepsilon \frac{\sigma_1 \sigma_2 \rho(1 + \delta) + \sigma_1^2(\delta - 1)}{r_2 - r_1 + \delta(r_1 + r_2)} + O(\varepsilon^2).$$

Now we obtain the competitive statistics of the variance with respect to  $\beta$ :

$$\frac{\partial v}{\partial \delta} = 4\varepsilon \frac{\sigma_1 \sigma_2 \rho r_2 - \sigma_1^2 r_2}{[r_2 - r_1 + \delta(r_1 + r_2)]^2} + O(\varepsilon^2).$$

Thus, when  $\frac{r_1 / \sigma_1}{r_2 / \sigma_2} < \frac{1}{\rho}$ ,  $\frac{\partial v}{\partial \delta} < 0$ . ■